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DISTRIBUTION, ABUNDANCE, AND AGE SEGREGATION OF BOWHEAD WHALES IN THE SOUTHEAST BEAUFORT SEA, AUGUST-SEPTEMBER 1986

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SUMMARY

Aerial systematic and photogrammetric surveys were conducted in the southeast Beaufort Sea during August and September 1986, to investigate the distribution, relative abundance, and age segregation of bowhead whales in relation to petroleum industry activities in the region. The study area extended from the 2-m isobath seaward between 141°W (Alaska-Yukon border) to 127°W (east of Cape Bathurst). Two systematic surveys of the study area were completed during the periods 25 August-1 September and 7-14 September. Photogrammetric surveys of portions of this study area were conducted from 25 August-1 September. Bowhead sightings recorded by L. Harwood (University of Alberta) and other researchers and by industry personnel during 1986 were also examined.

During the 25 August-1 September systematic survey, 41 bowheads were observed on-transect, another 27 were seen off-transect, and 11 were recorded during ferrying flights. Bowheads observed during the 7-14 September survey totalled 42 on-transect, 9 off-transect, and 70 during ferrying flights on 7 September. About 2,500 bowheads were estimated to be present in the study area during both survey periods, which is within the ranges reported for similar surveys in previous years.

The distribution of bowheads was similar during both survey periods. Most whales were located in an area in Mackenzie Bay about 40-60 km offshore of Shingle Point, within a band 40-100 km offshore of the eastern Tuktoyaktuk Peninsula, and near the Yukon coast and Herschel Island. Bowheads have been observed to congregate in each of these regions during some of the previous years of systematic surveys. It is likely that large-scale oceanographic phenomena lead to high densities of zooplankton in each of these areas during some years, and whales seen in these areas of concentration during 1986 appeared to be feeding.

A total of 109 bowheads was measured in the photogrammetric component of the study. As found in earlier studies conducted in the area, the population was geographically segregated by age. Only 24 per cent of the whales measured were mature, far less than the 60 per cent predicted for the population as a whole. Calves made up 5.5 per cent of the sample. The majority of bowheads measured off the Yukon coast and in Mackenzie Bay were sub-adults. Whales found on the Tuktoyaktuk shelf were predominantly adult, and most calves were also located in this area.

The surveys described in this report represent the seventh consecutive year of monitoring of the distribution and abundance of bowheads in the southeast Beaufort Sea during late August and September, and the sixth year in which data on the size classes of whales have been collected. Previous studies have documented considerable variation in the distribution patterns of bowheads both within and among years, and two hypotheses have been proposed to explain this variation. First, industrial activities in the region may have caused bowheads, especially larger, older individuals, to avoid the zone of industrial influence. Second, the distribution of bowheads in the region is

determined primarily by oceanographic features that influence the distribution of their food.

In 1986, there was considerably less industry activity in the southeast Beaufort Sea than in recent years, yet whales were still uncommon in the industrial zone. This suggests that the distribution of whales was determined by other factors, likely those influencing the distribution and abundance of their prey. However, mature whales were again under-represented in the photogrammetric sample, and the remaining portion of this component of the population was probably located outside the study area. Available evidence suggests that the distribution of bowheads in the southeast Beaufort Sea is naturally segregated by age class.

RÉSUMÉ

Durant les mois d'août et de septembre 1986, des sondages aériens et photogrammetriques ont été conduits dans le sud-est de la mer de Beaufort, pour étudier la distribution, l'abondance relative et la ségrégation tant qu'à l'âge des baleines franches en relation aux activités de l'industrie petroliere de la région. L'étendue de l'étude était de 2-m isobathe au large entre 141° ouest (la frontière Alaska-Yukon) jusqu'à 127° ouest (à l'est de Cape Bathurst). Deux sondages systématiques de l'étendue de l'étude ont été complétés pendant les périodes du 25 août-1er septembre et du 7-14 septembre. Des sondages photogrammetriques de parties de cette étude ont eu lieu du 25 août-1er septembre. Les records du nombre de baleines franches qui ont ètè vues par L. Harwood (Université de l'Alberta) et par d'autres chercheurs et aussi par le personnel de l'industrie ont aussi été examinés.

Pendant le sondage systématique du 25 août-1er septembre, 41 baleines franches ont été vues transversalement, 27 autres ont été vues non-transversalement et 11 ont été vues des airs. Pendant le sondage du 7-14 septembre, un total de 42 baleines franches ont été vues transversalement, 9 non-transversalement et 70 ont été observées des airs le 7 septembre. On estime qu'approximativement 2,500 baleines franches étaient présentes dans l'étendue étudiée pendant la période des deux sondages ce qui se maintient dans les limites de sondages d'années précédentes.

La distribution des baleines franches était semblable durant la période des deux sondages. La majorité des baleines était dans une étendue de la baie Mackenzie à peu près 40-60 km au large de Shingle Point, à l'intérieur d'une bande de 40-100 km au large de la péninsule est de Tuktoyaktuk, et prés de la côte du Yukon et de l'île Herschel. Un rassemblement des baleines franches a été observé dans chacune de ces régions pendant certaines années des sondages systématiques. Il semble que des phénomènes océanographiques de grande envergure amène de grandes densités de zooplancton dans chacune de ces régions certaines années et les concentrations de baleines qui ont été observées pendant 1986 semblaient se nourrir.

Un total de 109 baleines franches a été mesuré dans la partie photogrammetrique de l'étude. Comme il avait été découvert lors d'études menées dans cette région, la population était géographiquement ségréguée par âge. Du nombre des baleines mesurées seulement 24% étaient adulte, beaucoup moines que le 60% qui avait été prédit pour toute la population. 5.5% de cette étude comprenait des baleineaux. La majorité des baleines franches qui a été mesurée au large de la côte du Yukon et de la baie Mackenzie était sous-adulte. Les baleines près de Tuktoyaktuk étaient surtout adulte et la majorité des baleineaux était dans cette région.

Les sondages décrits dans cet exposé représentent la septième année consécutive de surveillance de la distribution et de l'abondance des baleines franches dans le sud-est de la mer Beaufort pendant les mois d'août et septembre, et la sixième année que des données concernant la dimension des classes de baleines ont été compilées. Des études précédentes ont documenté des variations considérables des patrons de la distribution des baleines

franches autant à l'intérieur qu'au travers des années, et deux hypothèses ont été suggérées pour expliquer cette variation. Premièrement, les activités industrielles de la région peuvent être la cause du fait que les baleines franches, surtout les plus grosses et les plus vieilles, évitent la zone d'influence industrielle. Deuxièmement, la distribution des baleines franches dansa la région est déterminée principalement par les traits océanographiques qui influencent la distribution de leur nourriture.

En 1986, il y avait beaucoup moins d'activité industrielle dans le sud-est de la mer de Beaufort que depuis quellques années, malgré celà les baleines étaient encore rares dans la zone industrielle. Ceci suggère que la distribution des baleines était déterminée par d'autres facteurs, possiblement par ceux qui influencent la distribution et l'abondance de leur proie. Toutefois, les adultes étaient de nouveau sous-représentés dans l'échantillon photogrammetrique, et la partie restante de ce groupe de la population était probablement située à l'extérieur de l'étendue de l'étude. L'évidence disponsible suggére que la distribution des baleines franches dans le sud-est de la mer Beaufort est naturellement divisée par classe d'âge.

INTRODUCTION

The bowhead whale (Balaena mysticetus) is a large, baleen whale found only in Arctic and sub-Arctic waters. As a result of intense commercial exploitation in the past, it is now one of the rarest cetaceans. The bowhead has been protected from commercial whaling since 1931, and is currently considered an endangered species by the Committee on the Status of Endangered Wildlife in Canada and the International Whaling Commission (IWC). The western Arctic population of bowheads is the largest of the five original stocks of the species. This population is thought to have originally contained 14,000 to 26,000 whales (Breiwick et al. 1981). Currently, it is estimated to contain 7,200 (± s.e. 2,400) animals (IWC in press).

The western Arctic population of bowheads migrates annually between wintering grounds in the Bering Sea and summering areas in the Canadian Beaufort Sea and Amundsen Gulf. During August and September, whales are present in areas of offshore oil exploration activity in the southeast Beaufort Sea. As a result of concerns regarding the possible effects of this activity on bowheads, the Government of Canada and the oil industry have sponsored studies to monitor the distribution, abundance, and behaviour of bowheads in this area each year since 1980. The present study, conducted in 1986, represents the seventh consecutive year of systematic aerial surveys for bowheads in the region.

Monitoring programs conducted since 1980 have shown that the late summer distribution of bowheads in the southeast Beaufort Sea varies markedly both within and among years. In 1980 and, to a lesser extent, in 1981, bowheads were common in the region of industrial activity off the eastern Mackenzie River delta and western Tuktoyaktuk Peninsula (Renaud and Davis 1981; Davis et al. 1982). During 1982 through 1985, however, whales were generally scarce in this area (Harwood and Ford 1983; McLaren and Davis 1985; Harwood and Borstad 1985; Duval 1986). Bowheads present in the industrial development zone have been primarily young animals, while the older component of the population (adult and near-adult) has generally been found outside this zone (Cubbage et al. 1984; Duval 1986; Davis et al. 1986; Cubbage and Calambokidis 1987).

Two explanations have been proposed to account for these variations in bowhead distribution (Indian and Northern Affairs Canada and Environment Canada 1984, 1985, 1987). First, it has been suggested that activities of the petroleum industry have either caused, or contributed to, a progressive exclusion of bowheads from the development zone because of behavioural disturbance. Older individuals may avoid the area as a result of previous experience. Alternatively, the distribution of whales varies naturally in response to the abundance and distribution of zooplankton, which is determined by large-scale oceanographic features in the area. The differential distribution of sub-adult and adult bowheads may reflect different habitat or feeding preferences.

Evidence from studies in recent years supports the hypothesis that distribution of bowheads in the southeast Beaufort Sea is controlled largely

by physical and biological factors that affect the distribution of their food. Harwood and Borstad (1985) and Duval (1986) observed that bowheads usually congregate near areas with distinct thermal and turbidity gradients depicted in satellite imagery. Such gradients indicate the presence of oceanic fronts and upwelling, features which may be associated with relatively high densities of zooplankton (Pingree et al. 1975; Mackas et al. 1980; Thomson et al. 1986).

This report describes the distribution, abundance, and age-class segregation of bowhead whales in the southeast Beaufort Sea in relation to activities of the oil and gas industry during late August and the first half of September 1986. Information for August was obtained primarily during aerial systematic and photogrammetric surveys conducted on behalf of the Environmental Studies Research Funds (ESRF). Systematic surveys in September and a reconnaissance survey in early October were undertaken by Harwood and Norton (1986) for Indian and Northern Affairs Canada and the U.S. Minerals Management Service. Sightings of bowheads from seal surveys, conducted by L. Harwood (University of Alberta) in the southeast Beaufort Sea during August and September 1986, are also included, as are incidental observations of whales by oil industry personnel during the 1986 drilling season.

METHODS

SYSTEMATIC SURVEYS

The timing, location, and procedures of the systematic surveys were designed to be as compatible as possible with similar bowhead monitoring programs conducted in recent years. The study area extended from 141°W (near the Alaska-Yukon border) to 127°W (east of Cape Bathurst), and from the 2-m isobath seaward. The northern boundary was 25 km beyond the 100-m isobath, except between 141°W and 138°W where it followed latitude 70°20'N. A grid of 26 north-south transect lines spaced at 20-km intervals was established in this study area (Figure 1).

The study area was surveyed during the period 25 August-1 September and again between 7-14 September 1986 (see Appendix A). The first survey was initiated about one week later than usual so that it could coincide with a study of bowhead food availability in the region (Bradstreet et al. 1987). Each survey began on the westernmost transect line and proceeded eastward. To allow comparison of the 1986 results with those from previous years, the study area was divided into the Yukon, Delta, Tuktoyaktuk Peninsula (Tuk Pen), and West Amundsen zones (see Figure 1), using boundaries established in 1981 (Davis et al. 1982). Ferrying flights to and from transect lines were flown over marine areas whenever possible to obtain additional information on the distribution of bowheads.

SURVEY PROCEDURES

Both surveys were conducted from a deHavilland DHC-6-200 (Twin Otter) aircraft chartered from Kenn Borek Air Limited in Inuvik, NWT. Two or three observers accompanied the pilot on each flight. During the August survey, the right observer occupied the co-pilot's seat and the left observer used the left window seat in the second row of passenger seats. The third observer occupied the right window seat in the second row of passenger seats. The left and second right observation positions were equipped with bubble windows. During the September survey, the two primary observers occupied the left and right positions in the second row of passenger seats. A third observer was present on 10 and 14 September, and occupied the co-pilot's seat. Any sightings made only by the pilot or third observer were classed as off-transect. Communication between the observers and the pilot was maintained through an onboard intercom system during all flights.

A survey altitude of 305 m (1,000 ft) was planned for all flights. The altitude was determined with a radar altimeter and was maintained at approximately 305 m for 61.6 per cent of the time spent surveying during August and 50.9 percent during September. For the remainder of the surveying time, the aircraft was maintained at an altitude of 152 m (500 ft). A previous study (Davis et al. 1982) found no difference in observers' ability to detect bowheads at these two altitudes. The planned ground speed was 200 km/h (110 kts) during surveys and 278 km/h (150 kts) during ferrying flights. Mean ground speed was 206.1 km/h during August and 206.7 km/h during September, but ranged from 187.6 to 229.8 km/h because of wind.

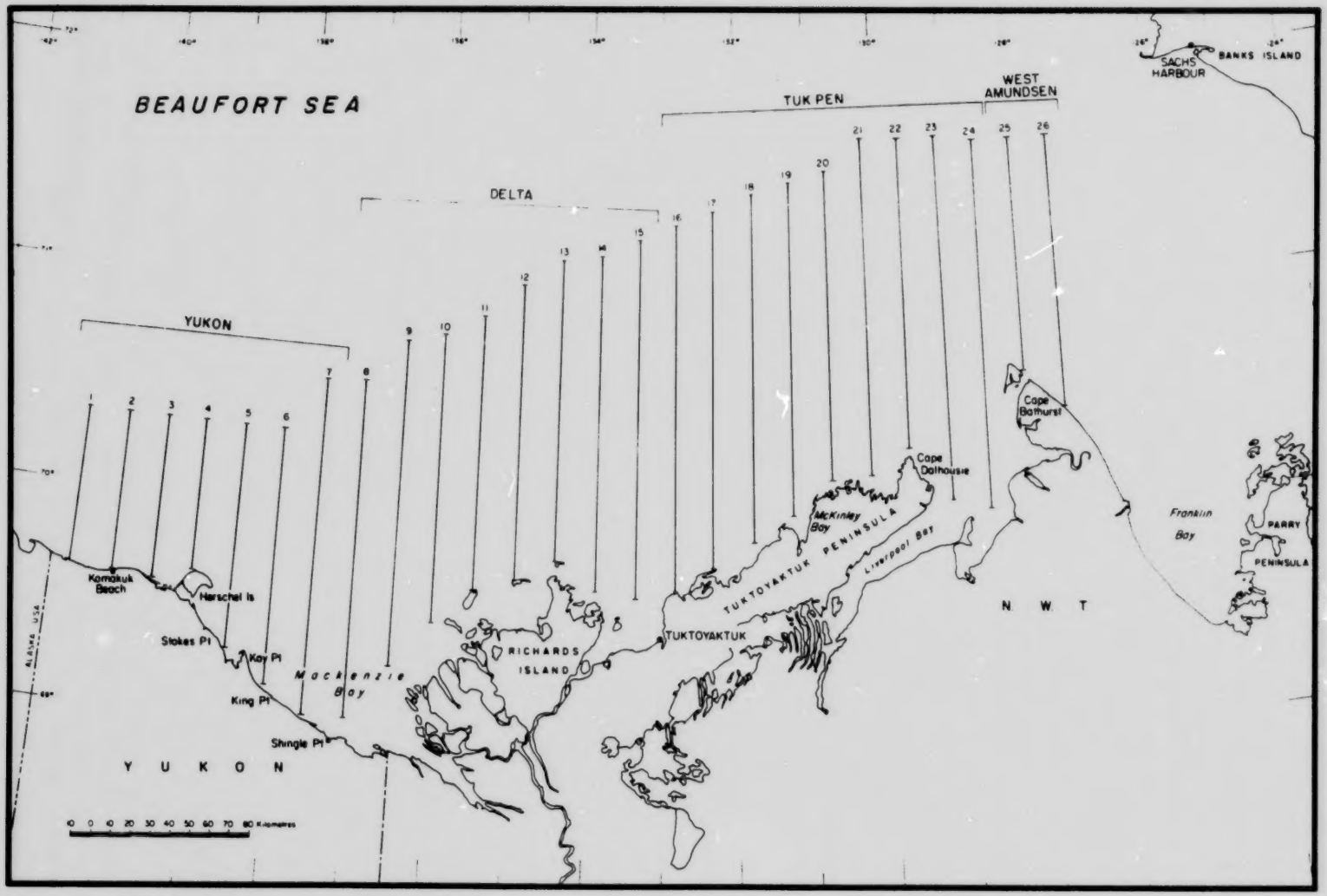

Figure 1. Transect lines and zone boundaries for the 1986 bowhead whales monitoring program.

Information on whales, seals, observation conditions, and survey locations were recorded immediately onto audio tapes and were later transcribed and transferred to data sheets. Tapes have been archived at ESL Environmental Sciences Limited, Vancouver, B.C.

At the start and end of each transect line, time (±1 s), observation conditions (including sea state, glare, wind, and wave direction), altitude, water colour, and ice type and cover were recorded by one or both primary observers. Any changes in observation conditions, sea state, altitude, water colour, or ice along the transect line were also recorded. In addition, the locations of any visible oceanographic fronts or accumulations of debris, as well as mobile and stationary industry activities, were noted by the observers.

Sea state was rated in accordance with the Beaufort Scale of Wind Force. Ice was classified as first-year or multi-year on the basis of colour, surface regularity, drainage pattern, and type and extent of ridging. Ice cover was classified using the following World Meteorological Organization (1970) categories: ice-free (0/10 cover), open water (<1/10 cover), very open pack-ice (1-3/10 cover), open pack-ice (4-6/10 cover), close pack-ice (7-8/10 cover), and very close pack-ice (9-9+/10 cover). Information on ice recorded during the surveys was supplemented with data obtained from the Atmospheric Environment Service (AES) (Environment Canada) office in Inuvik.

Observers recorded information on all marine mammals sighted during the systematic surveys and associated ferrying flights. Information recorded for each whale sighting included:

- species
- number of individuals
- time of sighting and/or location coordinates (see below)
- inclinometer reading or statement of on/off transect (see below)
- physical habitat associations (i.e., ice, sea state, water colour, visible fronts)
- relative age (calf, immature, or adult based on apparent size)
- approximate distance between individuals and group organization
- behaviour (i.e., apparent activity)
- direction and rate of movement with respect to compass headings and/or geographic features
- presence of birds or mud trails which would provide evidence of feeding
- sighting cue (e.g., movement, blow, or surfacing animal)
- proximity to geographic features
- unusual markings (e.g., scars) and location of white patch

The two primary observers on the systematic surveys scanned a 1,000-m wide area on each side of the aircraft, for a total transect width of 2 km. (The third observer during the August survey used a transect width of 400 m, when survey conditions were adequate for detecting seals, and a transect

width of 1 km at other times.) At an altitude of 305 m, the inner edge of the visible strip was 0 m from the flight path when the observer used a bubble window and 150 m from the flight path when the observer used the co-pilot's side window. To maintain equal viewing areas on both sides of the plane, the transect strip was 0 to 1,000 m when an observer used a bubble window and 150 to 1,150 m when an observer used the co-pilot's side window. Results of this study and previous monitoring programs show that detectability of bowheads across the transect width is essentially uniform (see Appendix B).

Whenever possible, the lateral distance of bowhead sightings from the flight line was measured with a Suunto PM-5-360 S inclinometer. The distance of the animal from the flight path was calculated by multiplying the cotangent of the angle of horizontal depression of the sighting by the aircraft's altitude (see Figure B-1B in Ljungblad et al. 1986a for an explanation of this method). The angle of depression was measured when the animal was abeam the aircraft.

DATA ANALYSIS

Bowhead Whales Within Study Area

Bowhead densities were calculated by zone to allow comparison of the 1986 results with those from previous years. Transect lengths used in determination of zone densities were obtained from the navigation system, and portions of the survey lines not surveyed because of fog were not included in the calculation. The uncorrected density of bowhead whales in each zone was calculated using the following formula:

$$\text{zone density} = \frac{\text{number of bowheads observed on transect}}{\text{transect length} \times \text{transect width}}$$

Zone densities were then corrected for bowheads not seen because they were submerged, and for the proportion of surfaced whales missed by observers. The combined results of a five-year study of bowhead behaviour indicate that the length of time whales spend at the surface and underwater are highly correlated with water depth (Würsig et al. 1985b). Although these data are used here to calculate a correction factor for bowheads beneath the surface, this factor should be considered approximate because of the documented variability in durations of dives and surfacings between years (Würsig et al. 1985b).

To correct abundance estimates for submerged bowheads, the proportion of time spent by whales at the surface was calculated for four depth categories: <16 m; 16-50 m; 51-100 m; and 101-250 m. Mean duration of surfacing (in 0.1 min) was obtained from Figure 10 in Würsig et al. (1985b) and was divided by total time (mean duration of surfacing plus mean duration of dive as read from the same figure) for each depth category. The resulting proportions were divided into unity to obtain the following correction factors: <16 m = 3.165; 16-50 m = 4.505; 51-100 m = 4.505; and 101-250 m = 7.812. The 16-50 m and 51-100 m categories were then combined.

Each on-transect bowhead sighting was assigned to one of the three depth categories using the Canadian Hydrographic Service chart 7080 (1973 printing). The number of on-transect bowheads within each depth category was summed for each zone and then multiplied by the appropriate correction factor. The estimated number of bowheads present within the area surveyed in each zone was obtained by adding the sums for the three depth categories. The zone sum was divided by the area surveyed to obtain a corrected density. The corrected density was then multiplied by the area of the zone to derive a corrected estimate of the number of bowheads in each zone. The size of each zone was determined from a 1:500,000 Mercator projection map. East and west boundaries were located 10 km beyond the easternmost and westernmost transect lines in each zone and the southern boundary was the 2-m isobath. Island and shallow (<2 m) areas were then subtracted from the total.

The zone estimates corrected for proportion of time at surface were then multiplied by 1.46 to account for bowheads present at the surface but not observed during the surveys. This factor was based on data from Davis et al. (1982), which suggest that observers do not see 31.5 per cent of the bowheads at the surface during systematic surveys. This correction factor was calculated from conditions and observers specific to the study by Davis et al. (1982), and the actual proportion of surfaced whales that were missed by observers in the present surveys may differ. For this reason, the corrected density estimates should be interpreted as broad indicators of abundance rather than precise measures.

Bowhead Whales Within Industrial Zones

To examine the distribution of bowhead whales in relation to the location of industrial activities in the region, the relative numbers of bowheads sighted inside versus outside the zones of industrial activity were calculated for each year from 1980 to 1986. The boundaries of the industrial zones were different from those of the geographic zones and were drawn using the yearly main zones of industry activity described by Richardson et al. (1985) and Duval (1986). The 1986 main industrial zone was defined according to the procedures used in previous studies (Norton and McDonald 1987), and is illustrated in Figure 2.

The boundaries of the industrial zone for each year were drawn on survey maps and the numbers of on-transect bowhead sightings within and outside these zones were tabulated. For each zone, these observed values were compared to the number of on-transect bowhead sightings expected on the basis of the area surveyed. The null hypothesis of no difference between the observed and expected values was examined using a chi-squared test.

PHOTOGRAMMETRIC SURVEYS

Survey Design

Aerial surveys were conducted from 25 August - 1 September 1986, to photograph bowhead whales in the southeast Beaufort Sea. A total of 28 h of air charter time was dedicated to this component of the study, which included ferrying and calibration time. These surveys generally were cued to the

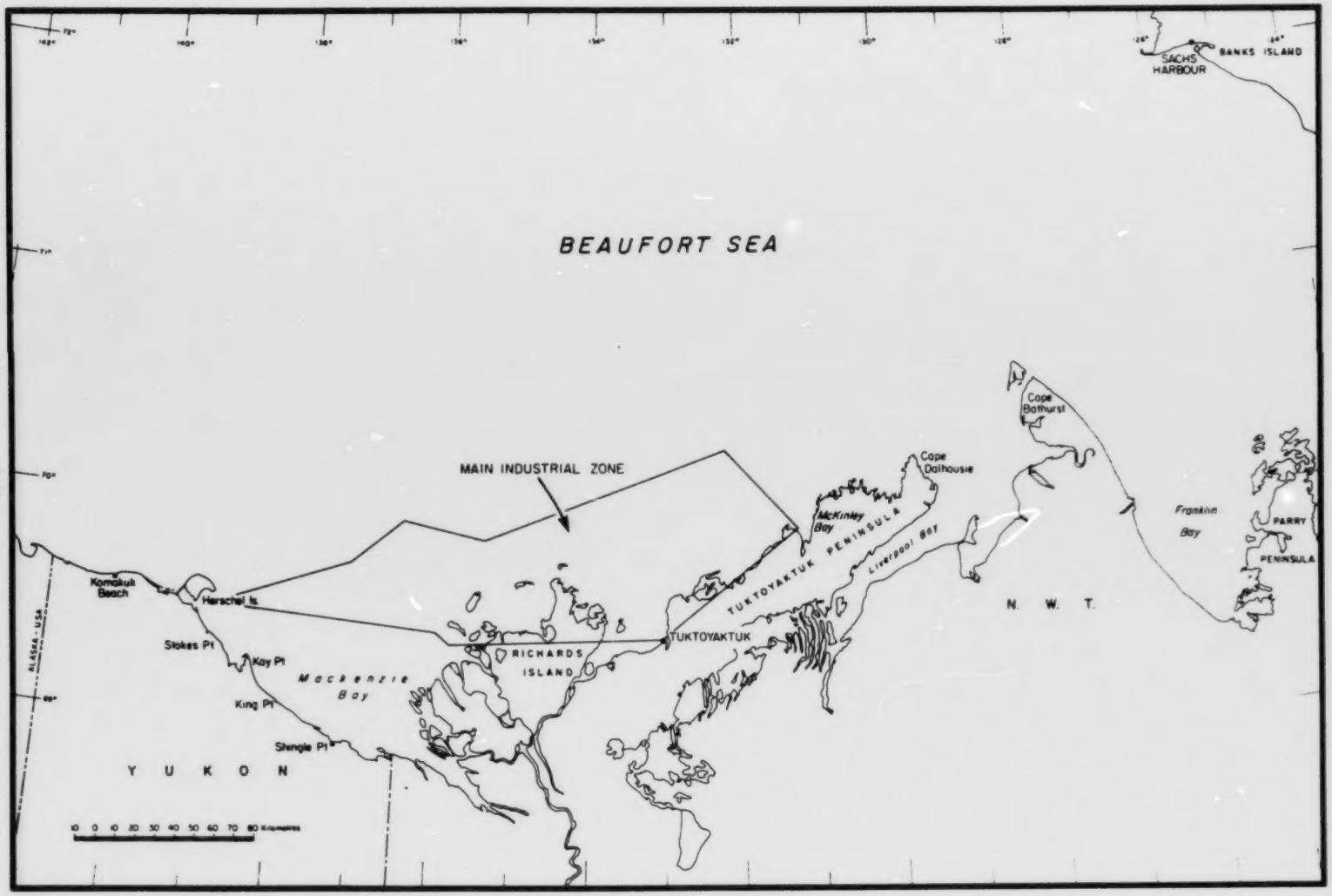

Figure 2. Location of the main industrial zone in the southeast Beaufort Sea, 1986.

location of bowhead whales determined by the systematic survey personnel. On one day that bowheads were not observed from the first plane, non-systematic lines were flown with the photographic plane to search for whales in other parts of the study area.

Survey Equipment

Photographic surveys were conducted from a deHavilland DHC-6-300 (Twin Otter) equipped with spare wingtip fuel tanks, bubble windows, an open camera hatch, and a computer-based data acquisition system. Photographs were taken with two cameras, one for subsequent measurement of whale lengths and one to identify individual whales from natural markings. The measurement camera was a 6 cm X 7 cm format Pentax equipped with a 105-mm lens. Fujichrome transparency film was exposed at ISO 200 or 400 depending on ambient lighting conditions. Photos for individual identification of whales were taken with a Nikon FE 35-mm camera equipped with a 180-mm lens, motordrive, and Fujichrome transparency film.

A custom-built, electronic level was fixed to the camera back to ensure that the film plane in the photogrammetric camera was parallel to the sea surface. This level signalled the camera operator through tones when the camera was more than 4° out of vertical alignment. A microcomputer was used to record navigation and altitude data directly from the aircraft avionics through an interface unit. The strobe output of the camera was also connected to the computer so that the computer automatically recorded exact altitude, location, and time when the shutter closed. Additional information related to each photo (e.g., group size and behaviour) was input to the computer via the keyboard. All data were held in computer memory so that photos could be taken in rapid succession. Aircraft position and sighting data were printed simultaneously and were recorded on computer diskette. Software to operate the data acquisition system was developed by Cascadia.

Photographic Procedure

Each day, the photographic surveys were initiated 2 to 3 h after the systematic survey aircraft departed from Inuvik. Observations of the systematic survey crew generally provided guidance regarding the location of whales. On the last survey day (1 September), the photographic plane left Inuvik first to continue photography in an area where bowheads had been sighted on the previous day. The photo surveys were conducted at an altitude of 225 m (750 ft) and air speed of 185-205 km/h (100-110 kts). Observers occupied the co-pilot's seat and cabin seats adjacent to bubble windows on each side of the aircraft. Observers and the pilot communicated via an intercom system during the survey. The observer in the co-pilot's seat was responsible for keyboard entry of data.

When one or more bowheads were sighted, the two observers in the main cabin moved to the camera hatch (approximately 45 cm x 60 cm) located in the floor at the rear of the aircraft. After the pilot oriented the aircraft in the direction of the whale at an altitude of 145 m and speed of 165 km/h (475 ft and 90 kts), the photo-identification camera-operator panned and took one to three photos as the whale came into view slightly forward of the aircraft.

The photogrammetric camera was fired once as the whale passed directly beneath the aircraft. Data on the camera level and frame numbers from the photo-identification camera were then relayed to the observer in the co-pilot's seat and were recorded on the computer. All photos were taken at 1/1000 s or 1/500 s.

Calibration and Verification Procedures

To calibrate the altimeter and the focal length of the photogrammetric camera, repeated flights were made over a target of known length. The target consisted of two strips of coloured sailcloth 15 m long with white bands sewn every 5 m. The strips were arranged in a cross with axes aligned parallel and perpendicular to the flight path. The strips were staked down and measured before and after the calibration flights.

To determine the accuracy and precision of calibration, measurements made photogrammetrically were compared to actual measurements of two verification targets. The targets were both 12.5 m long and were placed on airstrips at Shingle Point and McKinley Bay. Three photos were taken on 25 August and again on 26 August at Shingle Point, and 13 photos were taken on 1 September at McKinley Bay.

Grading Procedures

A list of photographs was compiled from the computer record after returning from the field. Images of whales and targets were measured with a binocular dissecting microscope at 25x magnification. An ocular reticle with a stage distance of 100 marks per 4.08 mm was calibrated with a stage micrometer to the nearest 0.01 mm. Images were measured to the nearest 0.04-0.02 mm, depending on the image quality. Measurements of whales were taken from the end of the rostrum (snout) to the notch in the flukes. Each image was given three grades: one for individual orientation according to the apparent flex of the whale in the vertical axis, and one each for fluke notch and rostrum tip resolution. Both grading systems had scales of one to five (Table 1). All images with views of the snout and fluke notch were examined and measured three times by a single observer. The average of the measurements was used as the basis for subsequent analyses. Flex and resolution grades were also averaged.

Calibration Target

Thirteen photographs of the calibration target form the basis of the system calibration. For each photo, measurements of the target were taken at 5, 10, and 15 m along the flight path, and at 5 and 10 m across the flight path. For each measurement, the photo scale (ratio of actual object size to object size on the film) was calculated. These were averaged to derive the photo scale (SM), which was then compared with the scale based on altimeter reading and nominal focal length of the lens (SA) for calibration. The relationship is described by the following equation:

$$SM = 49.3 + 0.969(SA) \quad (1)$$

TABLE 1

Grades of photo images used and recorded during bowhead image measurement

Grade	Description
Overall whale orientation	
1	Whale is straight, without apparent flex or arch.
2	Whale is slightly arched or flexed.
3	Whale is definitely arched or flexed.
4	Whale is severely arched and a measurement will certainly underestimate length of the animal.
5	Unacceptable
Rostrum tip and fluke notch resolution	
1	Good resolution; measurement point is clear and unequivocal.
2	Fair resolution; point is apparent but somewhat indistinct.
3	Poor resolution; point is barely visible and indistinct.
4	Estimate; point is obscured, but nearby clues (jaws, fluke tips, caudal peduncle) allow a reasonable estimate.
5	Unacceptable

Figure 3 indicates that the regression between the two parameters was highly significant (r^2 = 0.993, n = 13, $p << 0.001$). This equation simultaneously calibrates the nominal focal length of the camera lens and the nominal altitude determined by the radar altimeter. The equation derived to measure all whales and verification targets was:

Object size = Image size [49.3 + 0.969 (altitude/focal length)] (2)

Verification Targets

The photogrammetric measurements of the two, 12.5-m, verification targets were compared with true measurements (Table 2). The measurements obtained at the two sites were significantly different (t-test, $p < 0.05$), with values from Shingle Point and McKinley Bay averaging 12.48 m and 12.56 m, respectively. However, this small difference was equivalent to about 0.3 per cent of the mean. The difference in measurements would correspond to an altitude difference of 0.5 m at the 145-m level from which the photos were taken.

The precision of this system as measured from verification targets (0.5 per cent coefficient of variation) is higher than that reported for any other photogrammetric system used in bowhead measurement. It is emphasized that these results are based on measurements of verification targets that were independent of the calibration target, and were taken at different times in different locations than the calibrations.

Systematic Errors

Errors associated with radial lens distortion, film flatness, and distortion caused by aircraft motion and focal-plane shutter movement may all have contributed to the variance in measurements shown in Table 2. However, the magnitude of these errors remained the same throughout the survey and contributed no additional unmeasured systematic error. Possible differences in radar altimeter response over water and land have been identified as a source of error in photogrammetric measurement systems involving use of calibration targets on land. Nerini[1] measured targets on water and on land and found a significant, but small difference in measurements over the two substrates (no more than a 0.25 per cent difference between 137 m and 150 m altitude). A detailed discussion of possible sources of error in whale photogrammetry was provided in Cubbage et al. (1984).

Individual Identification

All slides and negatives were examined to determine the occurrence of recognizable individual whales in more than one photograph. Images were rated in terms of the degree of scarring or marks on whales that would allow reidentification in subsequent photos. Duplicate photos of animals were

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[1] M. Nerini, National Marine Mammal Laboratory, Seattle, WA, personal communication, 1987.

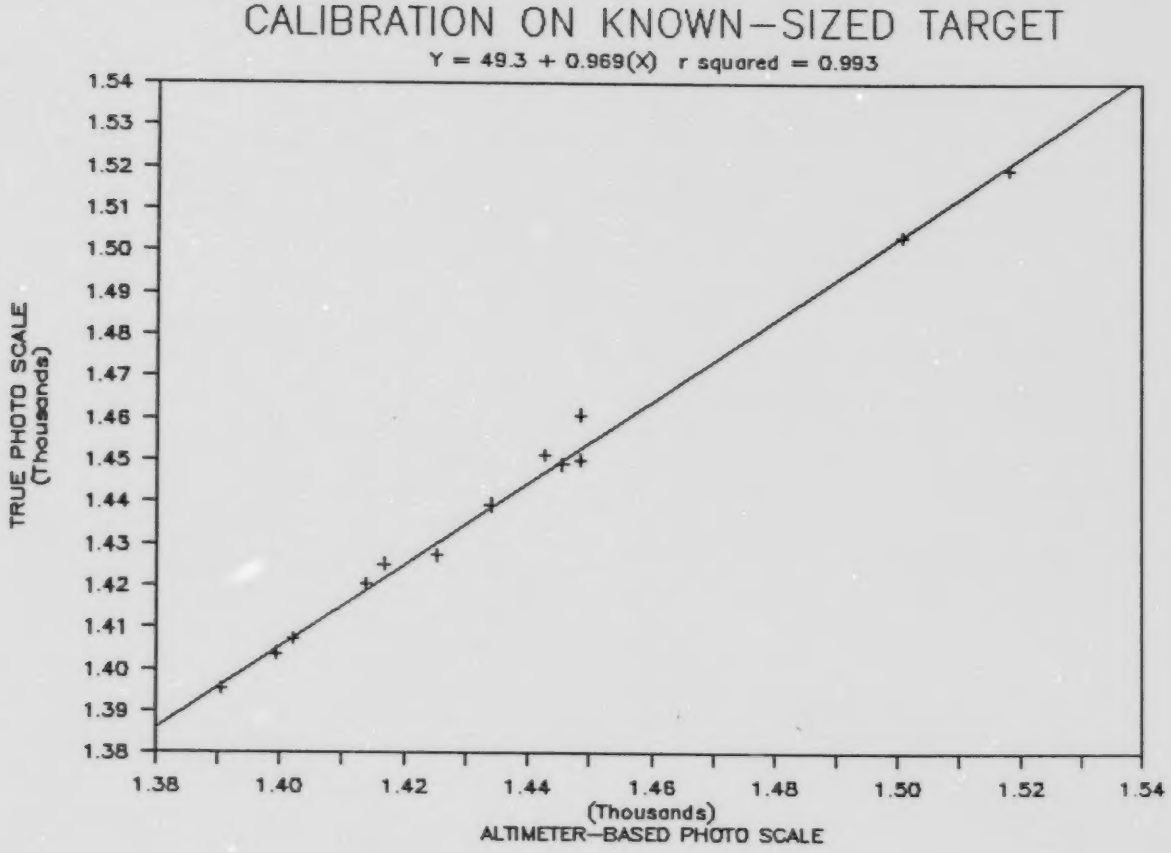

Figure 3. True photo scale (true length/photo image length) regressed on altimeter-based scale (altitude/focal length). N = 13.

TABLE 2

Lengths of verification targets measured through photogrammetry

Photo no.	Flight altitude (m)	Target length (m)	Measured length (m)	Error (m)	Error %
8	148	12.50	12.55	0.05	0.40
9	146	12.50	12.52	0.02	0.16
54	137	12.50	12.40	-0.10	0.81
58	144	12.50	12.56	0.06	0.48
59	150	12.50	12.47	-0.03	0.24
118	142	12.50	12.41	-0.09	0.73
192	140	12.50	12.58	0.08	0.64
196	149	12.50	12.53	0.03	0.24
197	150	12.50	12.49	-0.01	0.08
201	151	12.50	12.56	0.06	0.48
204	152	12.50	12.45	-0.05	0.40
205	146	12.50	12.49	-0.01	0.08
208	153	12.50	12.56	0.06	0.48
211	155	12.50	12.50	0.00	0.00
214	162	12.50	12.54	0.04	0.32
215	145	12.50	12.55	0.05	0.40
218	146	12.50	12.51	0.01	0.08
219	151	12.50	12.54	0.04	0.32
200	151	12.50	12.66	0.16	1.26
Mean		12.50	12.52	0.02	0.40

SD = 0.06 m

Coefficient of variation = 0.5% of the measured mean

obtained during the present investigation and were used to measure the variance in repeated measurements of individuals.

Repeat Measurements

Measurements of animals photographed more than once and identified on the basis of scars provided an indication of overall variability in the photogrammetric whale-length determinations. Table 3 shows the lengths of four animals that were measured repeatedly. There was greater variability in whale length measurements than the difference between actual and measured lengths of verification targets. The average variation in the lengths of individual whales was 0.7 per cent, whereas the comparable figure for the verification targets was 0.4 per cent (mean of the per cent error for each photo). Whale flex and reduced resolution of underwater images were most likely the primary reasons for the increase in variability during actual measurements of bowheads.

Unidentified Duplicate Whales

Duplicate measurements of the same animals must be removed to assure independence of size-class samples and, thus, validity of subsequent statistical tests. By removing duplicates on the basis of photo-identification of individuals with recognizable marks, the sample becomes biased away from older, more extensively scarred animals that are more readily identified (Davis et al. 1983). Therefore, for this study, potential duplicate animals were culled only on the basis of location and assumed swimming speed. All animals that were within sufficient range of another animal that a possibility of duplication existed were removed from consideration. This algorithm, described in detail in Cubbage et al. (1984), probably biased the sample toward solitary animals. Nevertheless, the resultant sample was not expected to be biased towards a given length of animal and, thereby, ensured independence of samples for later statistical tests.

Analysis of 1980 Data

Data from aerial surveys of bowheads conducted in the southeast Beaufort Sea in 1980 (Cubbage and Rugh 1982) were re-analysed during the present investigation to discern possible age-class segregation. Although whales were not measured photogrammetrically in these surveys, field biologists estimated the size class of animals according to four categories: calf, small, medium, or large. The same personnel estimated size classes during photogrammetric surveys in 1983 (Cubbage and Calambokidis 1987) and were then able to compare these four size categories with actual measurements obtained in that year. This comparison indicated that the broad size-class designations used in 1980 were likely accurate.

TABLE 3

Measurements of reidentified whales

ID no.	Photo no.	Grade			Length (m)	Diff[b] (%)
		Flex	Snout	Notch[a]		
86-37	1610	1.7	1.7	2.7	12.53	0.04
86-37	1730	3.0	2.0	3.0	12.52	
86-66	2381	1.7	2.0	2.0	13.06	0.4
86-66	2481	2.7	2.3	3.0	13.16	
86-67	2382	1.7	2.0	2.0	13.39	1.4
86-67	2482	2.0	3.0	3.0	13.76	
86-69	2420	2.7	2.7	3.0	12.04	1.0
86-69	2500	2.3	2.3	2.0	12.28	
				Mean difference	= 0.7%	

[a] See Table 1 for grade values.
[b] Diff = Difference of measurements from mean of two measurements as a percentage.

OTHER SOURCES OF BOWHEAD SIGHTINGS

Seal Surveys

Three systematic surveys for seals within the study area were completed on 21 August, and 5 and 23 September, 1986 by L. Harwood (University of Alberta). Timing of these surveys was such that one occurred before the August bowhead survey, one between the two surveys, and one after the September bowhead survey. Incidental sightings of bowheads obtained during these surveys are included in the analyses presented in this report.

Each seal survey involved the search of a localized area within the main bowhead study area. The specific area examined differed from survey to survey. North-south transect lines were established at equal intervals and were spaced as a function of the size of the area to be surveyed and air charter time available. Survey procedures followed during the seal surveys were similar to those used during the bowhead surveys. Observers occupied the left and right window seats in the second row of passenger seats and both viewing positions were equipped with bubble windows. The usual and planned transect width was 800 m (400 m on each side of the aircraft) and the survey altitude was 152 m (500 ft).

Late-Fall Reconnaissance Flight

On 3 October 1986, a reconnaissance survey was flown along the Yukon coast from the NWT-Yukon border to Herschel Island. Survey procedures during this flight were similar to those employed in the systematic surveys.

Marine Mammal Sightings by Industry Personnel

Information on bowheads, white whales, seals, and polar bears sighted by industry and support personnel in the southeast Beaufort Sea during the 1986 drilling season was provided both by Dome Petroleum Limited and by Gulf Canada Corporation. Only those whales identified to species were included in the present analysis. Ice observers were stationed on drillships and drilling units used by Dome. Whenever possible, these observers undertook dedicated wildlife watches lasting 15 min once every 3 h or at minimum three times a day. Incidental sightings of wildlife by other industry and support personnel on the drilling units and support vessels were also recorded.

RESULTS

DISTRIBUTION OF BOWHEAD SIGHTINGS

The distribution of bowhead sightings obtained during the 1986 field season in the southeast Beaufort Sea is discussed in the following sections. Sources of observations include the two systematic bowhead surveys in August-September, photogrammetric surveys in late August, seal surveys during August-September, a late-fall reconnaissance flight, and sightings by industry personnel. The location of bowhead whales sighted during the two systematic surveys are listed in Appendix C, and the location of bowheads observed during photogrammetric surveys are listed in Appendix D. Information on white whales obtained during these surveys and by industry personnel is described in Appendix E.

Systematic Surveys

The first systematic survey for bowheads was initiated on 25 August and extended over an 8-day period (see Appendix A). During several, brief periods, low-lying fog or cloud prevented continuation of the surveys to the planned end-point on several transect lines. Virtually the entire study area was ice-free during the field program. As in past years, the survey was initiated in the westernmost portion of the study area and progressed from west to east. Forty-one bowheads (30 sightings) were observed on-transect and another 27 (22 sightings) were recorded off-transect (Figure 4; and see Appendix C). Eleven bowheads were seen during ferrying flights, although these were not necessarily different animals than those found during the systematic survey.

Most on-transect bowheads were observed in an area in Mackenzie Bay about 40-60 km offshore of Shingle Point and along a band 40-100 km offshore of the eastern Tuktoyaktuk Peninsula (see Figure 4). There were a few sightings along the Yukon coast and only one bowhead was seen in Liverpool Bay. The pattern of distribution of off-transect and ferrying sightings was similar to that of on-transect sightings, except that bowheads were observed more frequently during ferrying flights within 5 km of the Yukon coast and off Herschel Island. One off-transect bowhead was observed about 45 km north of Komakuk Beach.

Three bowhead calves were sighted during the late August systematic survey. All were on-transect and located in the concentration area off the eastern Tuktoyaktuk Peninsula (see Figure 4).

The second bowhead survey was conducted from 7 to 14 September. The weather was favourable during this period, and only two transect lines (9 and 10) could not be surveyed. As in August, almost the entire study area (99.3 per cent) was ice-free. Although lines 25 and 26 were not attempted in September, a larger total area was surveyed than in August. Forty-two bowheads (33 sightings) were seen on-transect, and nine (8 sightings) were observed off-transect (Figure 5; and see Appendix C). About 70 bowheads were also sighted during the ferrying flights on 7 September.

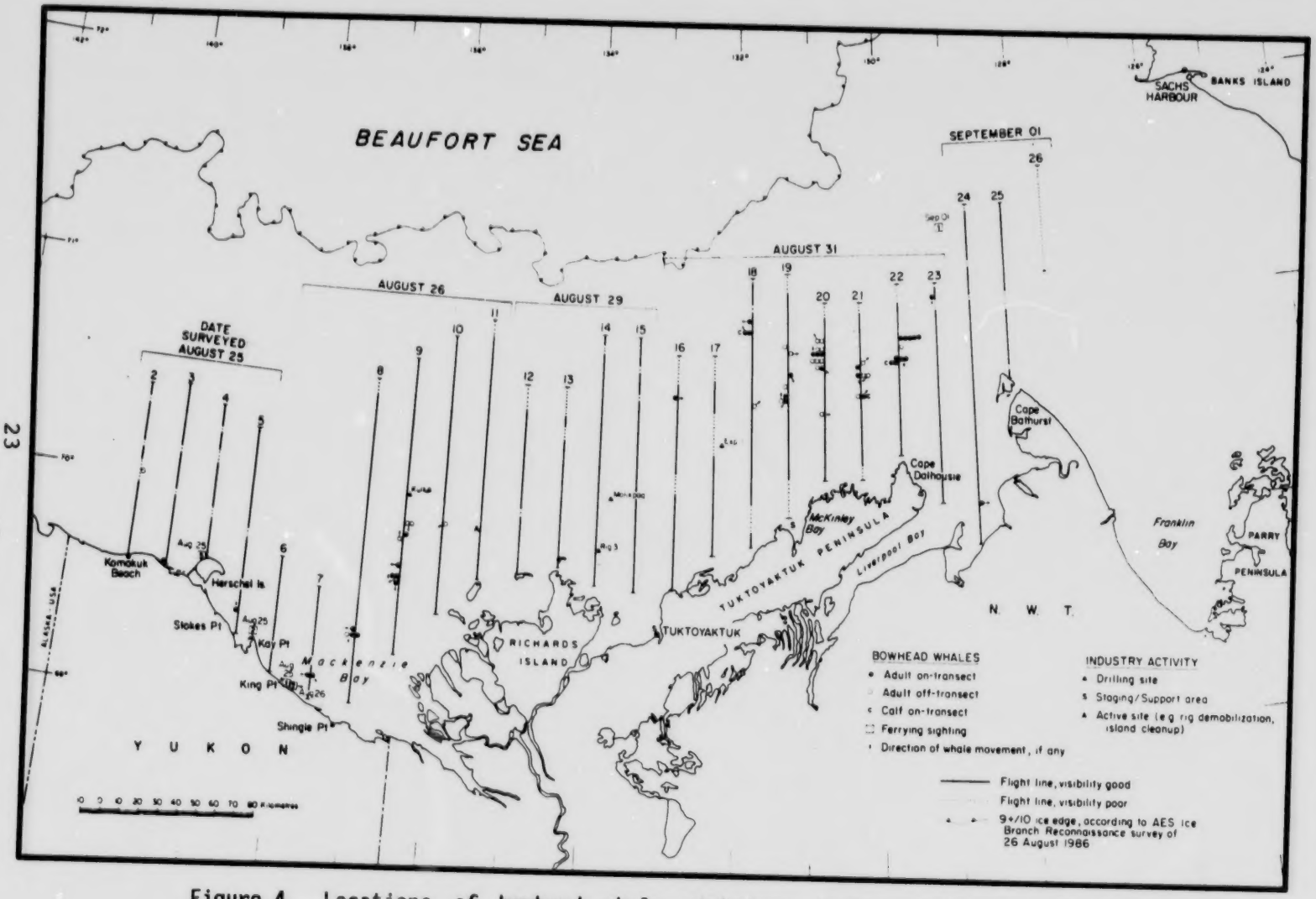

Figure 4. Locations of bowhead whale sightings during systematic surveys conducted from 25 August to 1 September 1986.

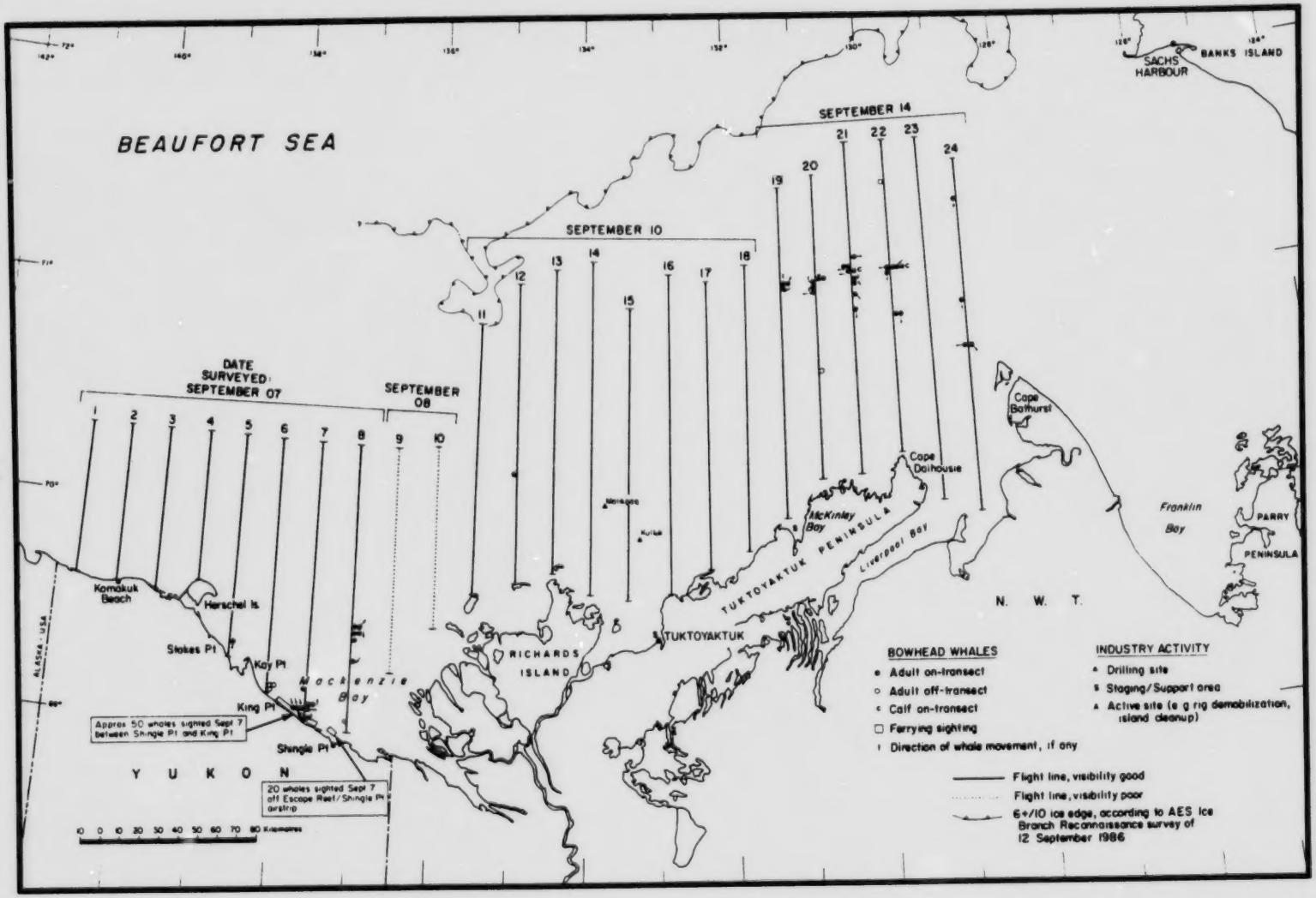

Figure 5. Locations of bowhead whale sightings during systematic surveys conducted from 7 to 14 September 1986.

The pattern of bowhead distribution observed during the September systematic survey was generally similar to that documented during the late August survey. The congregation areas noted offshore in Mackenzie Bay and off the eastern Tuktoyaktuk Peninsula in August were still evident in September. In the second survey, however, the congregation of whales off the Tuktoyaktuk Peninsula had narrowed and shifted to the north, and was centred about 100 km offshore. More whales were sighted along the Yukon coast in September than in August. For example, during a westbound ferrying flight on 7 September, about 50 bowheads were sighted between Shingle and King points, with the majority of these being located within 1 km of shore at King Point. On the eastbound return flight later that day, about 20 whales were seen close to Shingle Point. Unlike late August, no whales were observed near Herschel Island during September surveys. Two calves were sighted on-transect in September, and both were located in the concentration area offshore of the Tuktoyaktuk Peninsula (see Figure 5).

Group sizes of on-transect bowhead sightings were small during both the late August and September surveys. The observed number of bowheads per sighting averaged 1.37 and 1.27 in August and September, respectively. The largest on-transect group observed during the two systematic surveys contained five individuals. Three of these remained at the surface for as long as the group was in view (about 30 s). The largest group observed during the photogrammetric surveys contained four individuals.

Photogrammetric Surveys

During the late August survey, the photogrammetric survey personnel were usually directed to concentrations of whales by the crew on the systematic survey aircraft, and thus the sightings of the two study components were not independent. The distribution of whales measured photographically during 25 August - 1 September is shown in Figure 6. This distribution is similar to that observed in the concurrent systematic survey. Three bowhead concentration areas were observed north of the Yukon coast. In nearshore waters, a congregation of 20-25 whales was seen within a few kilometres of the northwest coast of Herschel Island, and another group of 10-15 bowheads was sighted about 10 km north of King Point. A minimum of 20 whales, including one calf, were observed in Mackenzie Bay, 40-60 km north of Shingle Point. On 31 August and 1 September, the photogrammetric survey team obtained 69 photographs of whales in a bowhead concentration area centered 50-80 km offshore of the eastern portion of the Tuktoyaktuk Peninsula, and also photographed one whale northwest of Cape Bathurst. Five of the animals photographed and subsequently measured off the eastern Tuktoyaktuk Peninsula were calves (whales <7.5 m in length, see Appendix D).

Other Sources of Sightings

Seal Surveys. The first systematic seal survey was conducted on 21 August 1986. The survey area extended from longitude 130°W to 134°W and from shore to about latitude 71°20'N. Fog prevented surveying the north ends of the easternmost two transects, but conditions were adequate in remaining areas.

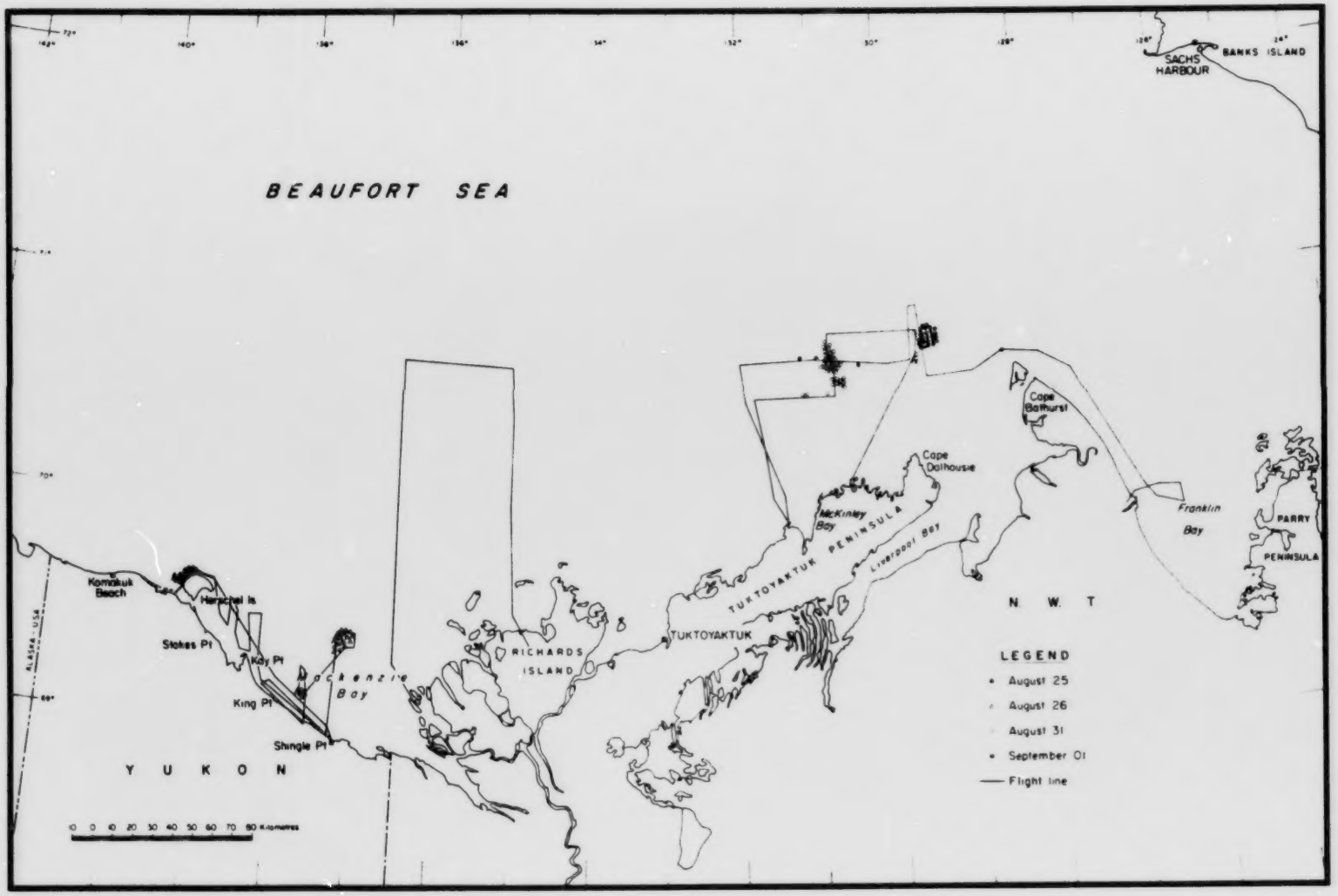

Figure 6. Locations of bowhead whales measured for length during photogrammetric surveys, 1986.

Thirteen bowheads (11 sightings) were recorded on-transect, including seven sightings of eight whales about 20 km northwest of McKinley Bay (Figure 7).

Bowheads were also sighted during the second systematic survey for seals conducted on 6 September (Figure 8). The area searched extended from longitude 136°35'W to 137°20'W, and from latitude 69°10-20'N to 70°00'N. Survey conditions were good or excellent on all four transect lines. Eleven bowheads (nine sightings) were recorded on-transect and one additional animal was observed off-transect.

Five on-transect sightings (eight whales) and one sighting during a ferrying flight were recorded during the third systematic seal survey completed on 23 September (Figure 9). The survey area ranged from longitude 129°25'W to 132°50'W and, for most of the survey, from latitude 70°40'N to 71°10'N. Survey conditions were poor compared to the earlier programs.

Late-Fall Reconnaissance Flight. A reconnaissance flight for bowheads was flown along the Yukon coast on 3 October during which 20 bowheads were observed (Figure 10). Fourteen of these whales were within 1 km of shore between Stokes and King points, and two were sighted off the northwest coast of Herschel Island. Others were further offshore and at Kay Point. The offshore area in Mackenzie Bay that contained many bowheads in both the August and September systematic surveys was also overflown on 3 October, but no whales were observed.

Sightings by Industry Personnel. Several bowheads were sighted by industry personnel in the vicinity of active exploration operations during 1986, but sightings of whales were fewer than in past years. This drop is most likely attributable to the reduced level of industrial activity during 1986, which provided fewer opportunities for industry personnel to observe whales. Four sightings of a total of six bowheads were recorded by industry personnel during the 1986 drilling season (see Appendix F). On 17 August, one bowhead was observed throughout the day near an anchor cable of the drillship Canmar Explorer at the Havik B-41 drilling site (70°20'N, 132°13'W; see Figure 3). Another bowhead was sighted at this location on 19 August. A single bowhead was observed on 30 July from the supply vessel Supplier 1 at 70°24'N, 132°06'W, and three bowheads were sighted at 70°21'N, 132°33'W on 18 August.

ABUNDANCE ESTIMATES

The uncorrected zone densities of bowheads for the two regional systematic surveys are presented in Table 4. These densities varied from 0 to 16.1 whales per 1000 square kilometres. The density of bowheads was consistently highest in the Tuk Pen zone, especially during the August survey. The density of whales in the Delta zone was comparably low during both the August and September surveys, whereas abundance of bowheads in the Yukon zone was higher in September than in August.

Bowhead densities corrected by depth category for submerged whales showed the same distribution pattern as the uncorrected densities (see Table 4). Most whales (43 of 63 sightings) were found in waters 16 to 100 m deep, whereas 19 sightings were in shallow water (<16 m) and one sighting was in

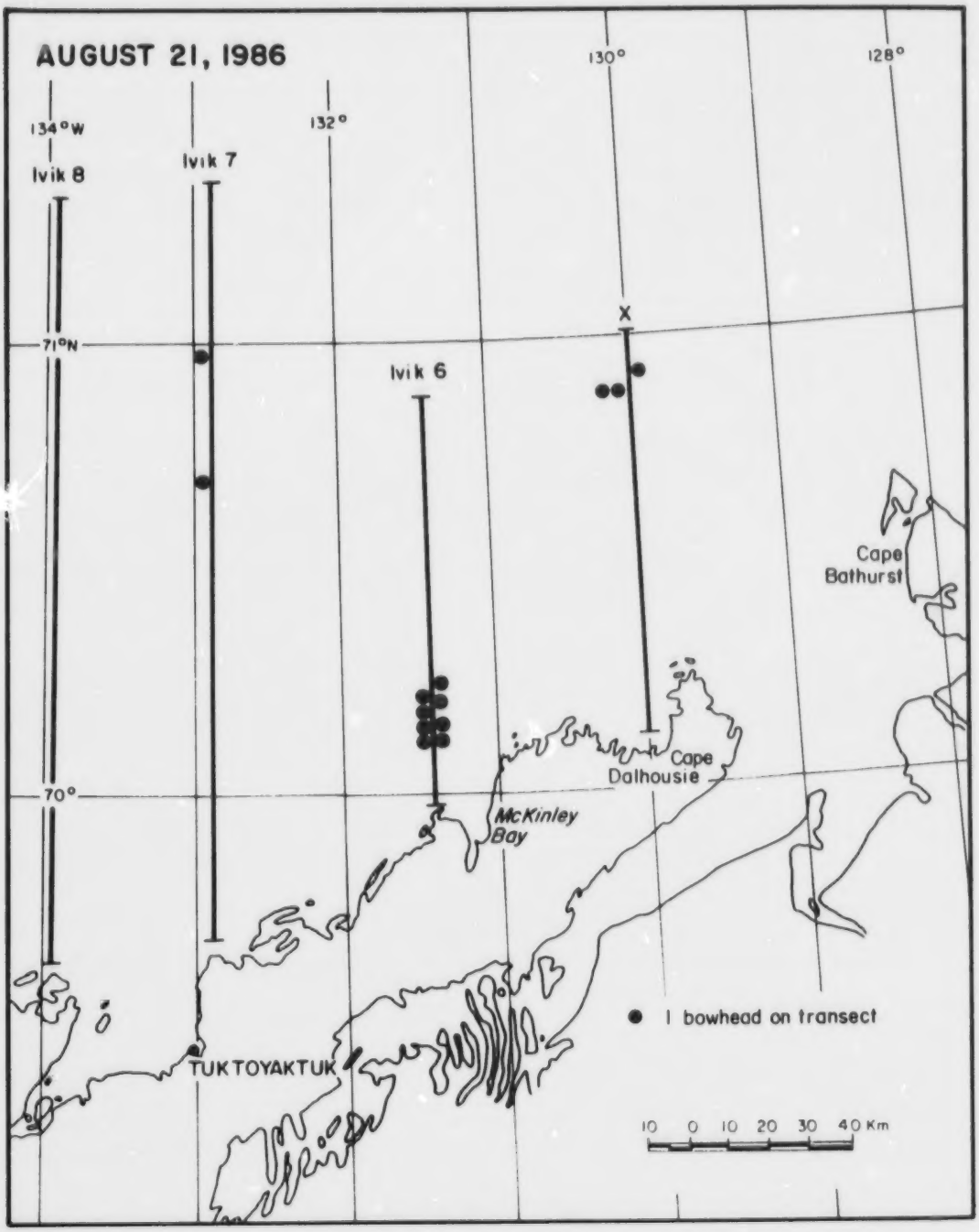

Figure 7. Locations of bowhead whale sightings during systematic seal survey, 21 August 1986.

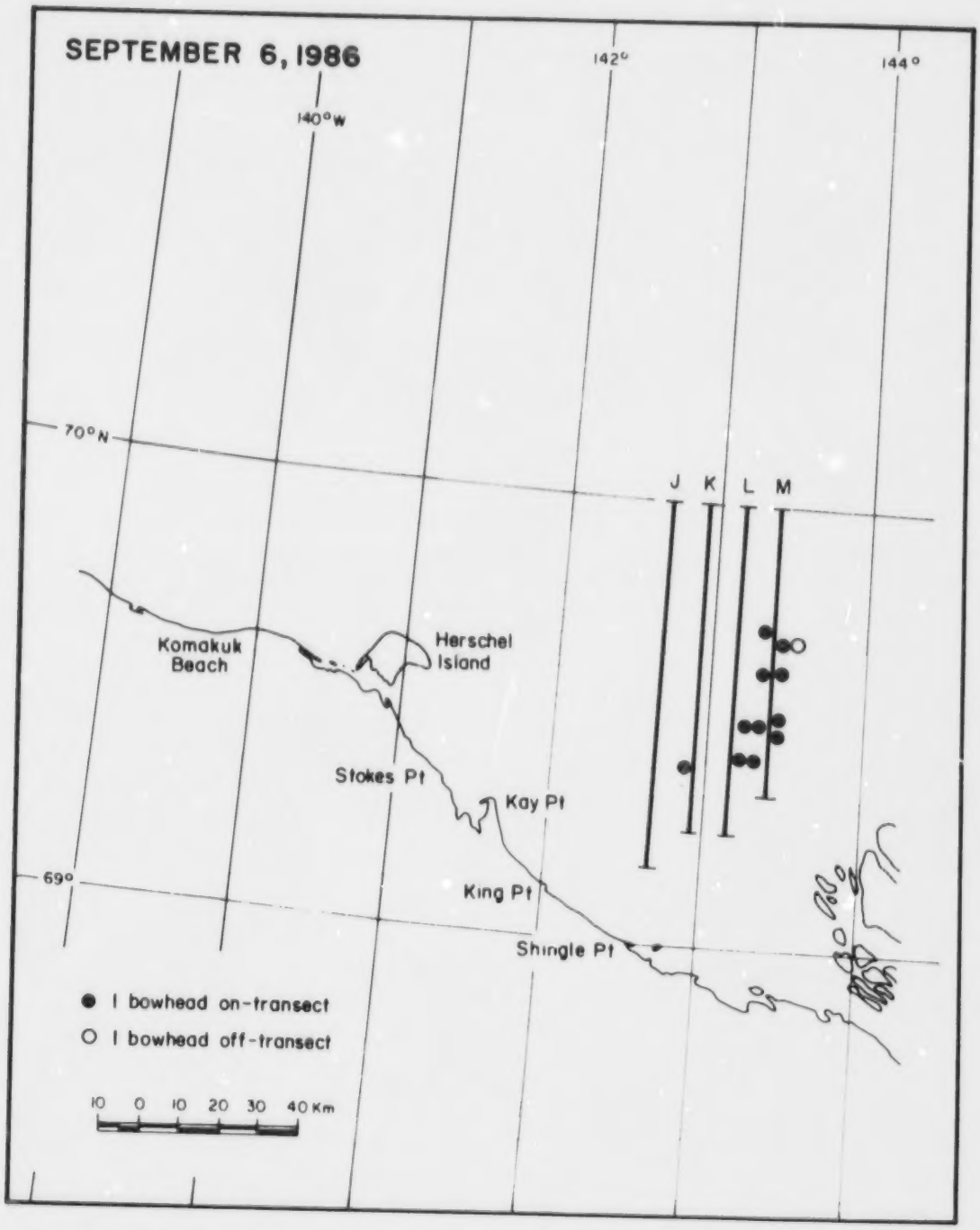

Figure 8. Locations of bowhead whale sightings during systematic seal survey, 6 September 1986.

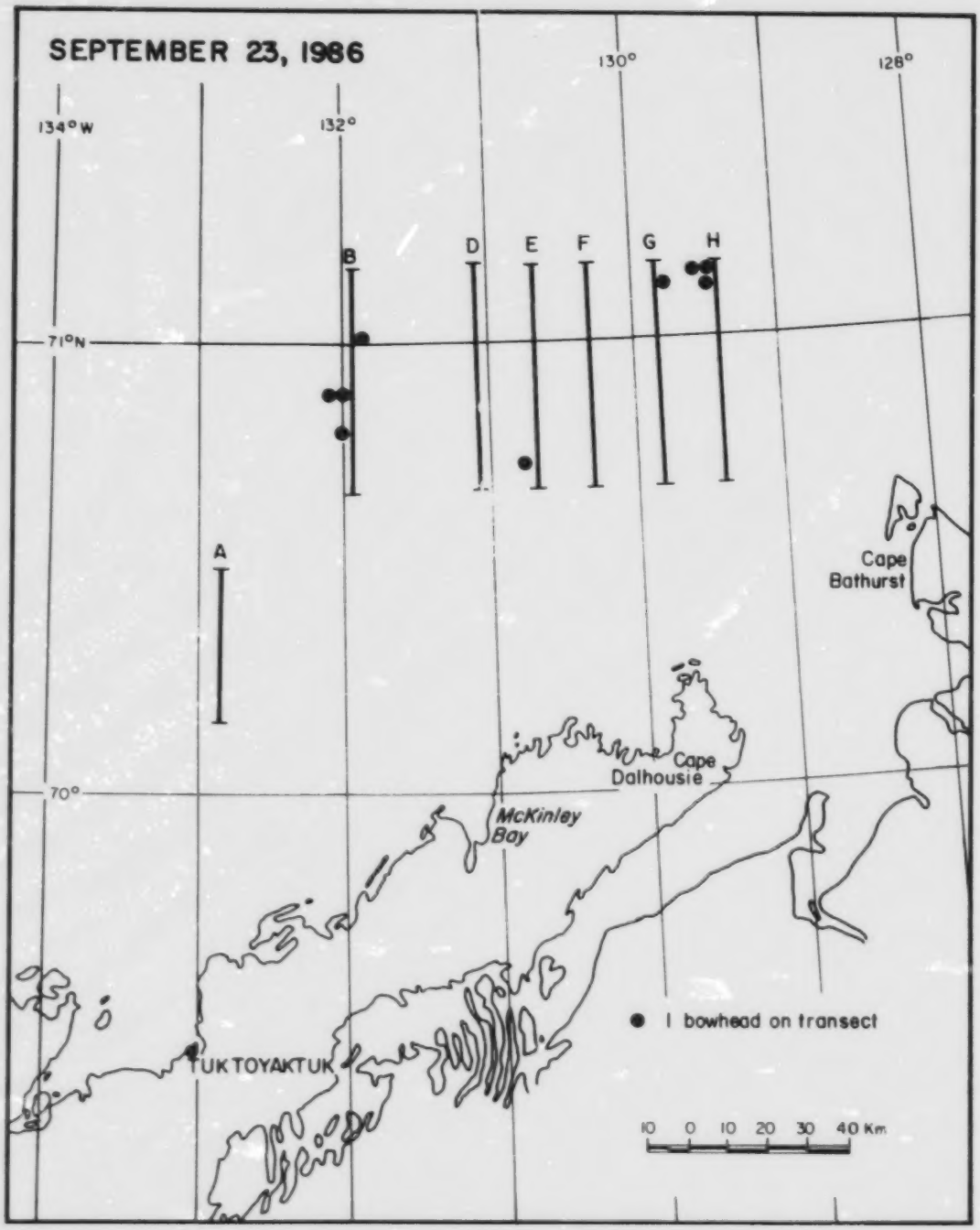

Figure 9. Locations of bowhead whale sightings during systematic seal survey, 23 September 1986.

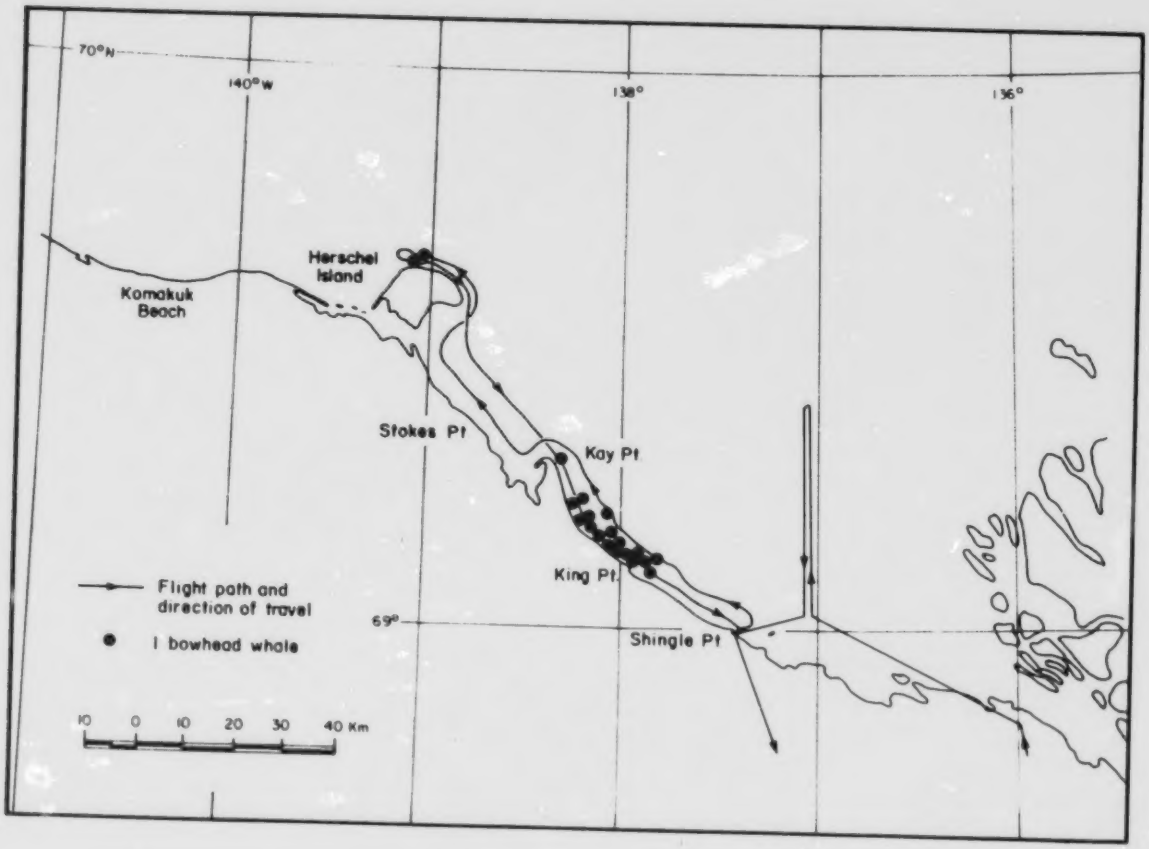

Figure 10. Locations of bowhead whale sightings during reconnaissance survey, 3 October 1986.

TABLE 4

Densities and estimated numbers of bowheads in the southeast Beaufort Sea, August-September 1986

Period		Zone				
		Yukon	Delta	Tuk Pen	West Amundsen	Total (pp)[a]
Aug 25 - Sept 1	no. on-transect (km surveyed)	4 897.4	8 1980.6	29 1800.6	0 163.4	-
	density = no./1000 km	4.5	4.0	16.1	0	-
	corr. density[b] = no./1000 km	17.1	13.5	71.8	0	-
	corr. estimate no. of whales present[c]	223	397	1924	0	2544 (35)
Sept 7 - Sept 14	no. on-transect (km surveyed)	10 1423.1	7 1804.6	25 2926.9	- 0	-
	density = no./1000 km	7.0	3.9	8.5	-	-
	corr. density = no./1000 km	23.2	15.2	39.6	-	-
	corr. estimate no. of whales present	482	407	1698	-	2587 (36)

a pp = percentage of population; assumes population size of 7,200 (IWC in press).

b density corrected for percentage of time at surface, based on depth; assumes bowhead whales are at the surface 31.6 per cent of the time while in areas <16 m deep, 22.2 per cent while in waters of 16-100 m, and 12.8 per cent of the time in waters with depths of 101-250 m (see Methods for calculation of depth correction factors).

c corrected estimate assumes 31.5 per cent of bowhead whales at surface were missed by observers (Davis et al. 1982).

deeper water (101-250 m). Total numbers of bowheads present during both surveys were estimated by applying a further correction factor to account for the proportion of surfaced whales missed by observers. It is emphasized that these estimates should be considered as rough approximations because of the limitations associated with application of correction factors (described in Methods). More than 2,500 bowheads were estimated to be present in the study area during each survey, which represents about 35 per cent of the total western Arctic bowhead population.

Table 5 summarizes data on the abundance of whales in the southeast Beaufort region during late August and early September from 1980 to 1986. The total abundance and numbers of whales estimated for each survey zone in 1986 are within the ranges reported in previous years. The estimated numbers of whales present in the Yukon and Delta zones in late August and September 1986 are lower than the averages for 1981-1986, but higher than the abundance estimates in some years. Bowheads were more abundant in the Tuk Pen zone in 1986 than the average for 1980-1986. The only previous survey period in which more bowheads were estimated to be present in this zone was late August 1980, when almost twice as many whales were present.

ACTIVITIES OF BOWHEADS

General activities of bowheads throughout the study area can be interpreted from observations of behaviour, movements, and habitat associations of whales during the systematic and photogrammetric surveys. Most of the bowheads observed during the August and September surveys were swimming slowly at the surface; a few were lying motionless at the surface. The direction of movement of whales sighted during the two systematic surveys (Figure 11) showed no strong directional trend in movement in either survey. Because most bowheads appeared to be feeding, it is probable that most movements were of a local nature.

Bowheads were concentrated in three areas during both the August and September systematic surveys: first, along the Yukon coast; secondly, in Mackenzie Bay, 40-60 km offshore from Shingle Point; and thirdly, over the continental shelf off the eastern Tuktoyaktuk Peninsula, from 40-100 km offshore from McKinley Bay and Cape Dalhousie. The activities of whales in each of these areas are discussed below.

Yukon Coast

Bowheads observed along the coast of the Yukon mainland and Herschel Island during the systematic and reconnaissance surveys appeared to be engaged mainly in feeding. Bowheads seen off the northwest coast of Herschel Island on 25 August were diving in shallow water close to shore, and may have been feeding at or near the bottom. A number of individuals defecated as they surfaced, which provides further evidence of feeding activity. Whales measured photographically in this area were all subadult (see results of photogrammetric surveys). On 7 September, whales observed along the Yukon coast were concentrated along a number of complex oceanographic fronts and also appeared to be feeding. Defecation at the surface was noted in one

TABLE 5

Estimated number of bowheads present in the southeast Beaufort Sea and western Amundsen Gulf, late August - early September, 1980-1986[a]

Times of Survey	Southeast Beaufort Sea				West Amundsen
	Yukon	Delta	Tuk. Pen.	Total	
Late August					
1980	NS[b]	NS	755	755	NS
1981	104	267	150	521	NC[b]
1982	319	67	120	506	NS
1983	50	21	118	189	NS
1984	30	36	71	137	21
1985	190	94	11	295	0
1986	40	81	296	417	0
Mean =	122.2	94.3	217.3	344.2[c]	
C.V.[d] =	92.7	94.2	116.3	47.2	
Early September					
1980	NS	NS	222	222	NS
1981	66	75	188	329	126
1982	290	42	30	363	NS
1983	10	110	193	313	NS
1984	260	18	39	317	84
1985	179	50	0	229	NS
1986	100	72	250	422	NS
Mean =	150.8	61.2	131.7	328.8[c]	
C.V. =	73.7	52.0	79.3	19.3	

a estimates include extrapolations for areas between surveyed transects, but no corrections for submerged or undetected animals. Survey areas varied in size from year to year. Data sources are: Davis et al. 1982, Harwood and Ford 1983, McLaren and Davis 1985, Harwood and Borstad 1985, Duval 1986, and present investigation.

b NS = not surveyed
NC = not calculated.

c 1980 deleted from calculation because of partial coverage of study area.

d C.V. = coefficient of variation.

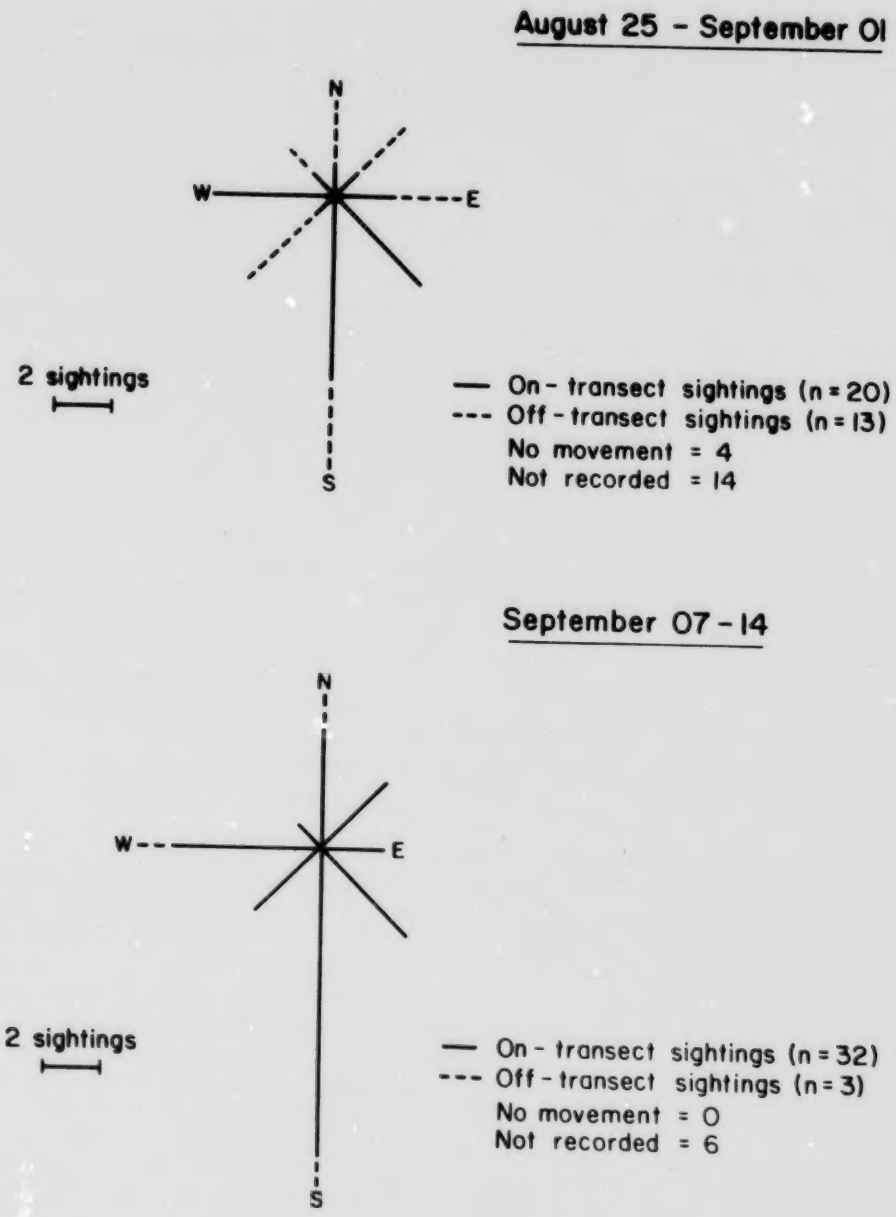

Figure 11. Observed direction of movement of bowhead whales sighted during systematic surveys, August-September, 1986.

sighting. Whales in this area appeared to be sub-adults. Bowheads sighted on the Yukon coast on 3 October were also apparently feeding.

Mackenzie Bay

Bowheads present in Mackenzie Bay during August and September (see Figures 4 and 5) were associated with the oceanographic front between turbid water of the Mackenzie River plume and clearer marine water. Whales were seen on both sides of this front, although most were on the less turbid side. Individuals were observed milling and turning at the surface, and were observed diving towards the front and surfacing and heading away from the front. As animals surfaced, mud or muddy water was usually seen flowing from their mouths, suggesting that whales were feeding at or near the sea floor on epibenthic or benthic organisms (Würsig et al. 1985a). Several animals in this area were observed defecating at the surface during the photogrammetric survey in late August.

Tuktoyaktuk Shelf

The density of bowheads in the area 40-100 km offshore from the eastern portion of the Tuktoyaktuk Peninsula was the highest observed in either the survey. Whales in this zone were predominantly adult, some of which were accompanied by calves. Several activity states were observed among bowheads in this region. Some whales observed from the photogrammetric aircraft in the vicinity of loose pack ice (approximately 2/10 ice cover) were lying motionless at the surface and apparently resting. Similar quiescent behaviour near loose ice has been documented by Würsig et al. (1984). One whale was seen slapping its tail flukes at the surface in a group of three socializing bowheads.

Most of the whales in this area appeared to be feeding either just under the surface or at depth. Some individuals were seen to dive steeply, fluking-up (raising the tail flukes above the surface) as they submerged. Water depths in the area are 40-50 m. A number of the animals photographed from the photogrammetric aircraft in August were swimming below the surface with their mouths open, indicating water-column feeding at shallow depths (Würsig et al. 1985a). Several whales defecated as they swam slowly at the surface. Many feeding whales in August were associated with distinct fronts separating relatively clear, blue-green water and more turbid, green water. Seabirds, ringed seals, and bearded seals were also concentrated along these fronts.

DISTRIBUTION OF BOWHEADS IN RELATION TO INDUSTRIAL ZONES

Oil exploration has occurred in offshore waters of the southeast Beaufort Sea since the late 1970s. The location and intensity of this activity has varied from year to year, but most has been centred off the Mackenzie River delta and eastern Tuktoyaktuk Peninsula north to the 100-m isobath (mostly within the Delta zone, see Figure 1). This area is referred to as the "industrial zone" (see Figure 2).

The level of offshore industry activity during 1986 was considerably less than in recent years, and the industrial zone was somewhat smaller. Only four

drillsites were active during late August (see Figure 4), which was reduced to two by early September (see Figure 5). In contrast, seven drilling units operated at a total of 15 sites during the same period in 1985.

Five bowheads were sighted on-transect within the industrial zone during the late August survey in 1986, which is not significantly different than expected on the basis of relative survey effort (chi-squared = 1.6, $p > 0.05$). However, no bowheads were sighted within this zone during the September survey, which is significantly less than would be expected if whales were distributed randomly with respect to the zone (chi-squared = 6.0, $p < 0.01$).

Systematic surveys of bowheads undertaken annually in the Beaufort region since 1980 have documented considerable variability in the abundance of bowheads present in the industrial zone, both within and between years (Table 6). In 1980, significantly more bowheads were observed within the industrial zone than outside the zone during late August, but no significant difference in abundance was apparent during early September of that year. Bowheads were evenly distributed inside and outside the industrial zone in late August 1981, but in early September significantly more whales were documented within the industrial zone. From 1982 to 1986, fewer whales than expected occurred within the industrial zone during both survey periods, with the exception of late August in 1984 and 1986, and early September in 1985, when no significant differences were evident.

BOWHEAD WHALE LENGTHS

Length Frequency

During about 28 h of survey time, including ferrying and calibration flights, 228 bowhead whales were photographed with the photogrammetric camera (see Figure 6). Images that had either resolution or flex grades worse than 3 in more than half the replicate observations were culled and were not considered further in this study. Four good-quality images of duplicate whales that were identified from scars were also discarded prior to analysis of whale lengths. After this screening, 109 individual whales of suitable quality remained for length determination. A histogram of the whale length frequency distribution is presented in Figure 12, and the location and length of each measured whale are indicated in Appendix D.

Adult bowheads are probably not less than 12.5 m in length (Cubbage et al. 1984, Nerini et al. 1984). Adult bowhead whales were under-represented in the 1986 sample, because no more than 24 per cent (26 out of 109) of the individuals photographed this year were mature.

Calves (animals less than 7.5 m long) represented 5.5 per cent of the sample (6 out of 109). Although biologically possible, this percentage must also be considered suspect because the evidence suggests that the 1986 length distribution data do not represent the population as a whole. The high frequency of animals in the 8.5 to 9.0 m class probably represents yearlings.

TABLE 6

Number of bowhead whales sighted on-transect inside versus outside industrial zonesa, late August and early September, 1980-86

Year	Zone	No. of whales Observed	Expected	Chi-squared	Prob.
Late August:					
1980	In	140	104.9		
	Out	15	50.1	36.3	$p < 0.001$
1981	In	24	26.3		
	Out	75	72.7	0.3	ns
1982	In	4	14.9		
	Out	47	36.0	11.3	$p < 0.001$
1983	In	1	8.7		
	Out	38	30.3	8.8	$p < 0.01$
1984	In	3	1.6		
	Out	11	12.3	1.4	ns
1985	In	1	7.8		
	Out	28	21.2	8.1	$p < 0.01$
1986	In	5	8.2		
	Out	41	32.8	1.6	ns
Early September:					
1980	In	22	23.2		
	Out	23	21.8	0.1	ns
1981	In	25	12.8		
	Out	18	30.2	16.6	$p < 0.001$
1982	In	2	12.1		
	Out	35	24.9	12.5	$p < 0.001$
1983	In	0	6.1		
	Out	29	22.8	7.7	$p < 0.01$
1984	In	1	5.5		
	Out	33	17.3	4.4	$p < 0.05$
1985	In	2	5.7		
	Out	21	17.3	3.2	ns
1986	In	0	5.8		
	Out	42	36.2	6.0	$p < 0.01$

[a] see Methods for definitions of industrial activity zones.

Sources: Renaud and Davis 1981; Davis et al. 1982; Harwood and Ford 1983; McLaren and Davis 1985; Harwood and Borstad 1985; Duval 1986; LGL Ltd., unpubl. data; present investigation.

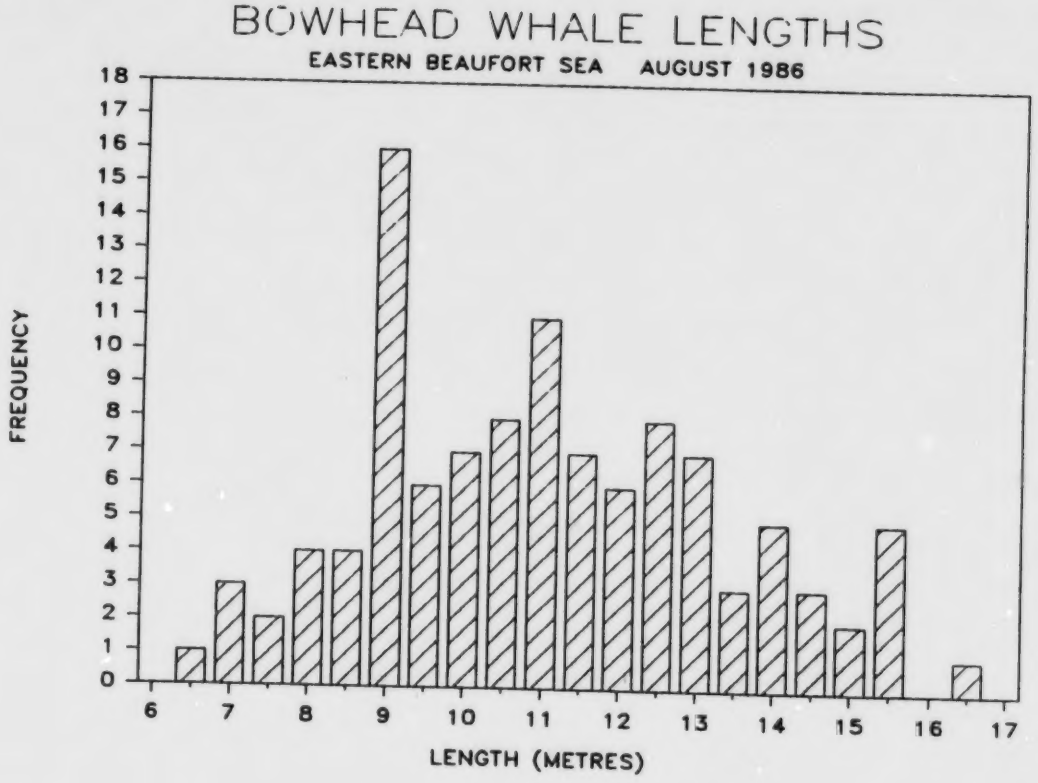

Figure 12. Frequency distribution of the lengths of 109 bowhead whales measured in 1986 from photos of acceptable quality.

Length by Location - 1986

Bowheads were found to be significantly larger in the eastern portions of the study area. Prior to examination of differences in the size composition of bowheads by location in the study area, possible duplicate observations on a given day were removed through the use of the location algorithm described earlier. The lengths of the remaining 29 whales showed a significant inverse correlation to longitude ($p < 0.01$). In a multiple-regression model with distance offshore, distance from the nearest industrial site (shorebase, operational island, or drillship), depth and longitude as independent variables, only longitude was significantly correlated with whale length. The lengths of the animals off the Tuktoyaktuk Peninsula were significantly different between successive days (ANOVA, $p < 0.05$) even though they occurred in roughly the same area (see Figure 6).

The proportion of presumably adult animals off the Tuktoyaktuk Peninsula still was unrealistically low when compared with the theoretical proportion of adults in a viable bowhead population (36 per cent vs >60 per cent calculated by Breiwick et al. 1984).

Comparisons to Previous Years

Photogrammetric surveys have been conducted in the Canadian Beaufort Sea each year since 1982. Table 7 compares size-class distributions documented over this period. When all areas are included in the analysis, the size-class distribution has varied each year other than in 1982 and 1983. Geographic segregation of size classes (Cubbage and Calambokidis 1987) in conjunction with different geographic coverage in surveys of the southeast Beaufort Sea each year could account for variation in size-class distribution observed among years. However, there is reasonable consistency in the size-class distribution since 1983 (see Table 7). The differences in size-class distribution within these four years are not significant (chi-squared, $p > 0.05$). This lack of age-class difference over a portion of the study area is apparent despite yearly changes in field personnel and equipment employed in measuring the whales from 1983 to 1985.

Length by Location - 1983, 1985, and 1986

To help determine possible causes of bowhead segregation and distribution by age class, simple and multiple linear regressions were calculated from a pooled dataset for 1983, 1985, and 1986. Lengths of whales were regressed against distance of animals from the closest industrial activity (drill ship, artificial island, or shorebase), distance from nearest shore, and longitude. Calves were not considered in this analysis because the smallest animals (calves) would be expected to occur in areas with the largest animals (adult females). The dataset consisted of 91 length measurements from 1983, 1985, and 1986, with possible daily duplicate individuals removed as described earlier. Chi-squared analysis showed no significant difference between the lengths before and after the screening to remove duplicate animals ($p > 0.10$). Locations of measured animals and industrial activities for all three years of the analysis are shown in Figure 13.

TABLE 7

Comparison of bowhead whale lengths in the eastern Beaufort Sea by size class, 1982-1986.

Year	Source[a]	n	No. of whales by size class		
			<10m	10-12m	>12m
All areas					
1982	1	361	96 (27)[b]	99 (27)	166 (46)
1983	2	197	54 (27)	49 (25)	94 (48)
1984	3	391	153 (40)	119 (30)	119 (30)
1985	4	47	26 (56)	16 (34)	5 (11)
1986	5	109	43 (39)	32 (29)	34 (31)
Mackenzie Bay area only[c]					
1982	1	250	60 (24)	76 (30)	114 (46)
1983	2	91	37 (41)	39 (43)	15 (16)
1984	3	238	120 (50)	90 (38)	28 (12)
1985	4	44	25 (56)	16 (36)	3 (7)
1986	5	40	22 (56)	14 (35)	4 (10)

[a] Source: 1. Davis et al. 1983
2. Cubbage et al. 1984
3. Davis et al. 1986
4. Duval 1986
5. present study.

[b] Percent of whales in each size class.

[c] Mackenzie Bay area extends to roughly latitude 70°N west of the Delta to Herschel Is.

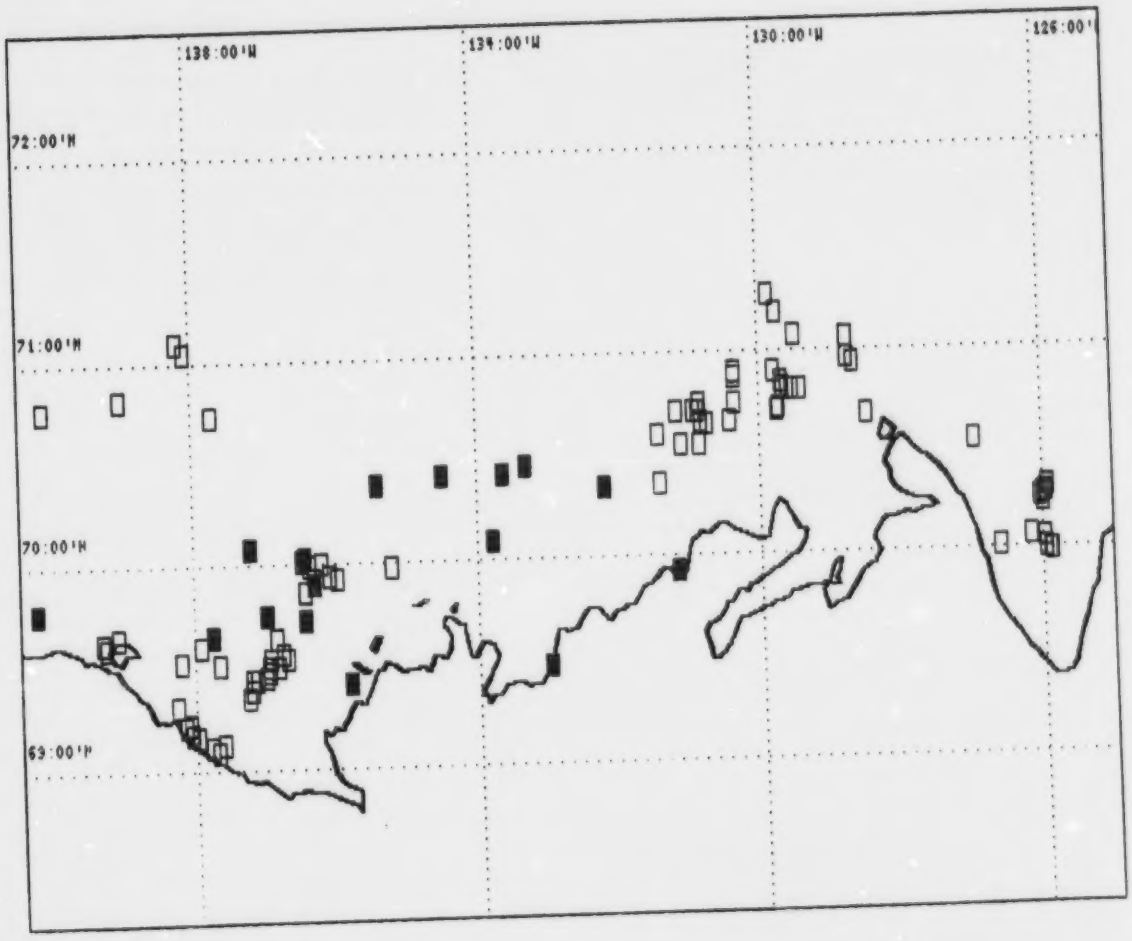

Figure 13. Locations of measured bowhead whales and industrial sites in 1983, 1985, and 1986. All potential duplicate whales removed by methods described in text. Open squares = bowheads, closed squares = industrial sites.

In simple regression models, distance from shore, distance from industrial activities, and longitude were each individually significant predictors of whale length ($p < 0.01$). To test the extent to which some predictors were better than others, the three significant predictors were re-analysed together in a multiple-regression model. Distance from shore and distance from industrial activity were significant predictors of whale length in this model ($p < 0.02$), whereas longitude was not a significant factor ($p = 0.06$) (Table 8).

In 1983, large whales were found in Franklin Bay, at a considerable distance from industrial activity in the region. However, this area was not surveyed in 1985 and 1986. A different model emerges if the Franklin Bay portion of the sample from 1983 is removed so that the analysis includes only those animals that could be affected by industrial activity. Distance from industrial activity is no longer a significant predictor of whale length (see Table 8). In a model that does not consider distance from industrial activity, distance offshore and longitude are highly significant ($p < 0.01$) predictors of length of bowheads west of Cape Bathurst.

Length Estimates - 1980 versus 1983

In 1980, bowhead whales occurred in large numbers within the industrial zone. Although no photogrammetric measurements of whale lengths were attempted in that year, observers conducting aerial surveys estimated sizes of whales according to four classes; small, medium, large, and calf (Cubbage and Rugh 1982). The same observers also conducted research in 1983 that involved both photogrammetry and subjective evaluations of whale size, thereby allowing comparison of the two measurement systems. Estimated length categories compared with the 1983 measurements are shown in Table 9.

Figure 14 shows the locations of bowheads assigned to various age classes in 1980. Given some confidence in the observers' abilities to estimate broad size classes, lengths of whales found in the 1980 concentration area in the industrial zone off the Tuktoyaktuk Peninsula can then be compared with measurements from 1983 in the Delta zone and off Cape Dalhousie. Frequencies of calves, and small- and medium-sized whales were grouped and compared with large whales (Table 10).

The size classes of bowheads in the industrial zone during 1980 are more similar to those observed off Cape Dalhousie in 1983, an area away from industrial activity, than those in Mackenzie Bay in 1983. In 1980, both large animals and calves were observed relatively close to the Tuktoyaktuk Peninsula near zones of industrial activity. Overall frequencies of size classes were not different between 1980 and 1983 (Fisher's exact test, $p = 0.09$). The results of this analysis support the hypothesis that large whales have been displaced by industrial activity in the region and have moved to areas beyond sites of industrial operations. However, ice conditions in 1980 were unusually severe, which resulted in a delay of several weeks in the timing of spring migration of bowheads past Point Barrow (Ljungblad et al. 1986b). This delay may have significantly altered the normal patterns of whale distribution and segregation during the late summer of this year.

TABLE 8

Multiple linear regression results of variables compared with whale length; 1983, 1985, and 1986

Independent variable	Tolerance	Probability
Longitude	0.42	0.06
Offshore distance	0.99	0.01
Industry distance[a]	0.42	0.02

Note: N = 91. Possible daily duplicate whales removed. Multiple $R^2 = 0.37$, $p < 0.001$.

[a] Distance from nearest drillship, dredge, or shore base

Same as above without animals in Franklin Bay 1983

Independent variable	Tolerance	Probability
Longitude	0.66	0.06
Offshore distance	0.84	0.01
Industry distance[a]	0.58	0.55

Note: N = 79. Multiple $R^2 = 0.23$, $p < 0.001$.

[a] Distance from nearest drillship, dredge, or shore base.

TABLE 9

Comparison of estimated lengths with mean measured lengths of bowhead whales

Category	Mean	SD	N
Small	8.0	1.6	6
Medium	11.6	2.2	53
Large	14.7	1.1	25

(ANOVA, $p < 0.001$)

TABLE 10

Comparison of estimated lengths of bowhead whales by region and year

	Location	Year	Ca,Sm,Me[a]	Large	Comparison 3	Comparison 2
1	Tuk Peninsula	1980	124	42	NS	*
2	Mackenzie	1983	32	3	*	
3	Cape Dalhousie	1983	6	5		

[a] Pooled classes of calf, small- and medium-sized animals.
* $p = 0.01$; NS ($p > 0.01$), Fisher's exact test.

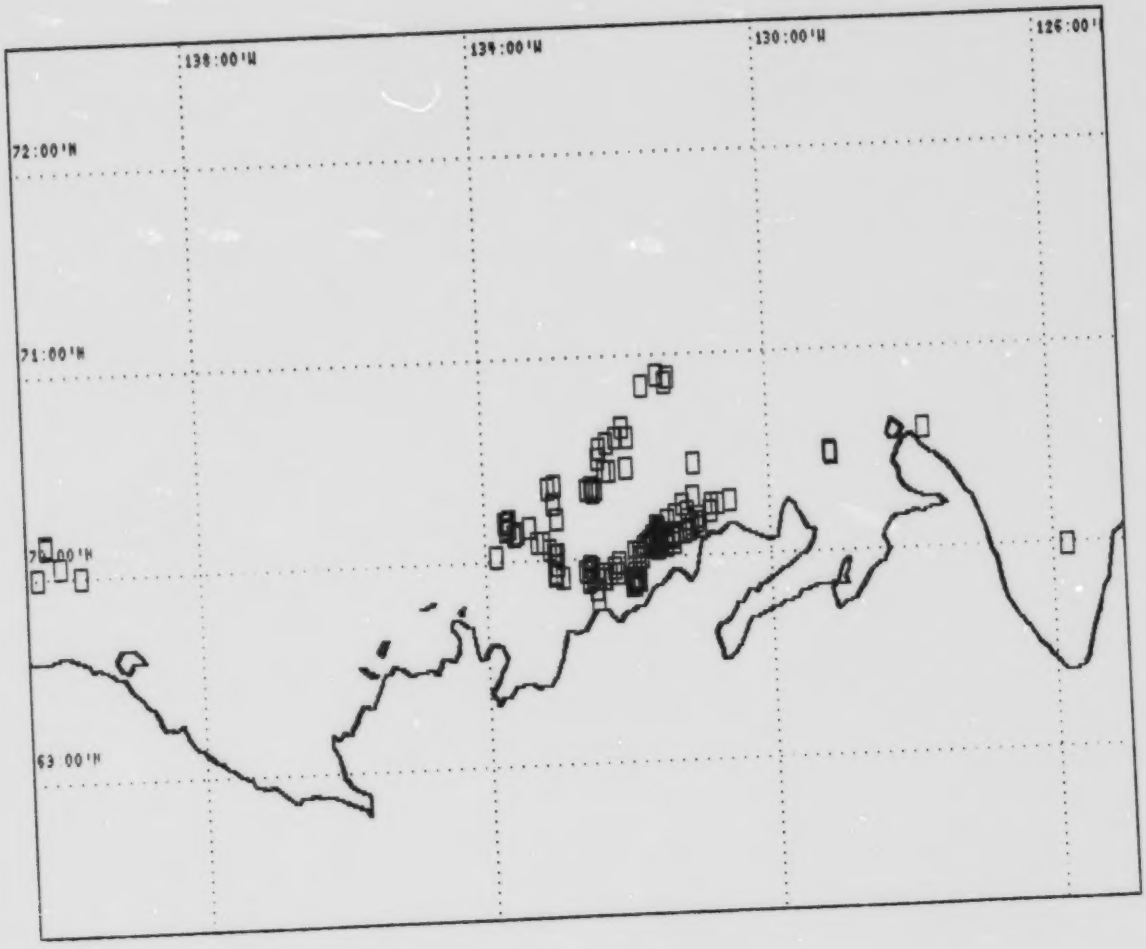

Figure 14. Locations of bowhead whales estimated into size classes in 1980.

DISCUSSION

GENERAL PATTERNS IN 1986 AND PREVIOUS YEARS

The abundance and distribution of bowheads in the southeast Beaufort Sea varies considerably both within and between years. Environmental factors thought to influence bowhead distribution in the region in any given year include the direction and duration of wind events and the location and extent of pack ice (Harwood and Borstad 1985; Duval 1986; Thomson et al. 1986). Wind creates upwelling in some areas and influence the location of the Mackenzie River plume. These and other oceanographic features affect the abundance and distribution of zooplankton, which in turn are expected to influence the movements of bowheads. The relationship between oceanographic and meteorological phenomena and the distribution of bowheads is discussed in detail in Borstad (1985), Harwood and Borstad (1985), Duval (1986) and Thomson et al. (1986).

Bowheads were found congregating in three relatively well-defined areas in 1986. Only 13 of 119 whales (11 per cent) sighted on- and off-transect during the two systematic surveys were outside these areas. These three areas have also contained concentrations of bowheads in some, but not all, previous years in which surveys have been conducted. Patterns of occurrence of bowheads in each concentration area in 1986 and recent years are discussed separately below.

Yukon Coast

In 1986, whales were observed close to the Yukon coast between Shingle and Kay points, and off the northwest coast of Herschel Island, but numbers fluctuated over the season. R. Barnes (DFO, Inuvik, cited in Harwood and Norton 1986) reported about 50 bowheads along the Yukon coast during a reconnaissance flight on 15 August 1986, but fewer whales were observed in the area 10 days later during the systematic surveys. By 7 September, bowheads had returned to the area in considerable numbers, and many were still present on 3 October, the last date that the Yukon coast was surveyed in 1986.

The numbers of bowheads present in nearshore waters off Herschel Island also varied over the 1986 season. The area was surveyed by personnel from the Naval Oceans Systems Center, who reported seeing about 20 bowheads close to the northwest shore of the island on 20 August, but none on 24 August[2]. However, 20 to 25 whales were observed at this location on 25 August during the present investigation. No bowheads were sighted near Herschel Island during systematic or reconnaissance surveys on 7 September, but at least a few whales had returned by early October.

The Yukon coast between Kay and Shingle points is generally one of the most consistent concentration areas for bowheads in late summer. During the 1970s, whales were often sighted in this area (Fraker and Bockstoce 1980).

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[2] S. Moore, Naval Ocean Systems Center, personal communication, 1986.

During the 1980s, nearshore concentrations were observed in late August or early September of 1983 to 1986 (McLaren and Davis 1985; Harwood and Borstad 1985; Duval 1986), but no such concentrations of bowheads were apparent in 1981 or 1982 (Davis et al. 1982; Harwood and Ford 1983). Although bowheads may be found along the Yukon coast in most years, the abundance of animals within a given season appears to vary. In 1986, concentrations of whales were noted between 15 August and 3 October, but numbers of animals varied over the seven weeks. In 1985, many bowheads were observed in the area over at least two months (mid-August to mid-October) and at least five weeks in 1984. In the 1983 season, however, the coastal congregation of whales apparently lasted only about two weeks.

The coast of the Yukon mainland and nearshore waters of west and northwest Herschel Island appear to be important feeding areas for bowheads. Whales have been observed feeding here in past years (Harwood and Ford 1983; McLaren and Davis 1985; Harwood and Borstad 1985; Duval 1986), as well as during the present investigation. Analyses of satellite imagery suggest that upwelling and other oceanographic phenomena in this area may lead to high densities of zooplankton (Borstad 1985; Harwood and Borstad 1985; Duval 1986). Zooplankton surveys conducted off the Yukon coast in 1985 indicated the presence of large numbers of the estuarine, warm-water copepod Limnocalanus macrurus (Bradstreet and Fissel 1986). Similar surveys in the vicinity of feeding bowheads near King Point in late August 1986, documented high densities of large calanoid copepods and hydrozoans (Bradstreet et al. 1987). This area contained a higher biomass of zooplankton than other locations sampled in 1986, including the western edge of the Mackenzie plume and off the Tuktoyaktuk Peninsula[3]. It is not known if lower densities of zooplankton occurred along the Yukon coast in those years when whales were absent (e.g., 1981 and 1982).

Bowheads found along the Yukon and Herschel Island coasts are predominantly sub-adult (Cubbage et al. 1984; Duval 1986; Davis et al. 1986). All animals measured in this area during the present study were smaller than 12.5 m, the length at which animals can be considered adult. Factors attracting younger animals to this area or causing older bowheads to be absent are not yet known.

Mackenzie Bay

Bowheads sighted offshore in Mackenzie Bay during 1986 were associated with the western front between the Mackenzie River plume and colder, clearer marine waters. This congregation was observed during bowhead surveys on 26 August and 7 September, and during seal surveys on 5 September. No whales were seen in this area on the 3 October reconnaissance flight, nor was a distinct front between estuarine and marine waters visible then.

Bowheads appeared to be feeding intensively along estuarine fronts, apparently on benthic or epibenthic organisms. Concentrations of feeding whales along similar fronts in the same general area were also observed during

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[3] M. Bradstreet, LGL Ltd., personal communication, 1987.

surveys in 1982, 1984 and 1985 (Harwood and Borstad 1985; Duval 1986). Bowheads in these years were also seen surfacing with mud streaming from their mouths, suggesting that they were feeding on or near the bottom.

Physical convergence at estuarine fronts separating warm fresh water and more saline waters in offshore areas results in local congregations of plankton, which may attract bowheads to Mackenzie Bay in some years (Griffiths and Buchanan 1982; Borstad 1985; Harwood and Borstad 1985). Analyses of zooplankton samples obtained at the Mackenzie plume edge in late August 1986, have been undertaken by Bradstreet et al. (1987). Results of this study provide information on the types and densities of zooplankton potentially used by bowheads in this area in 1986. As on the Yukon coast, bowheads in Mackenzie Bay in 1985 and 1986 were predominantly sub-adult (Duval 1986; present study).

Tuktoyaktuk Shelf

During surveys on 31 August and 1 September 1986, bowheads were congregated in a band roughly 50 to 80 km north (70°35'N to 70°50'N) of the eastern Tuktoyaktuk Peninsula between McKinley Bay and Cape Dalhousie. When this area was surveyed again on 14 September, the band had narrowed and shifted north to be centred about 100 km offshore (70°50'N to 71°10'N). Nine bowheads were later sighted in this area during a seal survey on 23 September, despite poor survey conditions (see Figure 9). Therefore, it is probable that this offshore concentration persisted over a period of at least three weeks in 1986.

Some bowheads have been documented offshore of the Tuktoyaktuk Peninsula during each year since 1980, but densities comparable to those observed in 1986 have only been apparent in 1980 and 1983. In early August 1980, large numbers of whales were sighted in waters north of the Mackenzie Delta. This concentration shifted eastward during August, and, by the end of the month, many animals were present in the vicinity of the 1986 congregation area on the Tuktoyaktuk shelf (Renaud and Davis 1981). As in 1986, the centre of this concentration area shifted offshore during early September in 1980. No large congregations of bowheads were apparent in this area during 1981 or 1982 (Davis et al. 1982; Harwood and Ford 1983), but, in September, 1983, whales were again present in considerable numbers over the eastern Tuktoyaktuk shelf in the same general area as the concentration in 1986 (70°40'N to 71°10'N, McLaren and Davis 1985). Analyses of historic bowhead whaling data for 1891 to 1906 suggest that whales often congregated in this region during August (Fraker and Bockstoce 1980).

In 1980, 1983, and 1986, most bowheads were distributed over the continental shelf within water depths of 100 m. In other years (e.g., 1981-1982), whales have been sighted further offshore near the shelf break (>100 m depth). It has been suggested that upwelling in the vicinity of the shelf break and associated thermal fronts over the Tuktoyaktuk shelf may lead to the presence of relatively high densities of zooplankton in this area (Borstad 1985; Harwood and Borstad 1985). The presence of large numbers of ringed and bearded seals, in addition to bowheads, suggests that the Tuktoyaktuk shelf may be a highly productive feeding area in some years. Although the types of

food consumed by bowheads in this area are unknown, sampling conducted on the Tuktoyaktuk shelf in 1986 (Bradstreet et al. 1987) indicate the diversity and abundance of available zooplankton. Photogrammetric surveys in 1986 and previous years indicate that bowheads found on the Tuktoyaktuk shelf are predominantly adult, and sightings of calves also are most common in this region.

Areas Unused in 1986

Previous bowhead monitoring studies in the southeast Beaufort Sea from 1980 to 1985 have identified concentration areas that were apparently unused by bowheads in 1986. In August 1980, bowheads were present in high densities north of Richards Island (Renaud and Davis 1981). A comparable abundance of whales has not been observed in this area during any surveys conducted since 1980. Some minor congregations of bowheads were present near Richards Island in 1981, but most whales in this year were located in the deep-water Herschel Canyon area north of Herschel Island (Davis et al. 1982; Thomson et al. 1986). Bowheads were also abundant in the latter area in 1983, but not from 1984 to 1986.

Waters to the north and east of Cape Bathurst and Franklin Bay supported relatively large numbers of bowheads in the late summers of 1981 (Davis et al. 1982), 1983 (Cubbage et al. 1984), and 1984 (Harwood and Borstad 1985), as well as during the historical whaling period (Fraker and Bockstoce 1980). In 1986, few whales were seen off Cape Bathurst during the systematic surveys, and Franklin Bay was not within the study area.

AGE-CLASS SEGREGATION OF BOWHEADS

Aerial surveys conducted during this study and in recent years indicate that a significant proportion of the western Arctic bowhead population occurs outside of the study area during late August and early September. Photogrammetric studies during the same period have shown that adult animals are under-represented in samples from the southeast Beaufort Sea, indicating that a large proportion of adults in the population must be elsewhere during that time. The small percentage of mature animals observed is inconsistent with results of population modelling and cannot be considered to be representative of the population as a whole. Breiwick et al. (1984) provide evidence that mature bowheads must comprise at least 60 per cent of the population. The location of these adult whales is largely unknown. Some bowheads have been observed off the north coast of Alaska during this period (Ljungblad et al. 1986b). Whales close to shore tend to be sub-adult, and those farther offshore are predominantly adult (Richardson et al. 1986).

A likely area of occurrence of the remaining adult component of the population is Amundsen Gulf and adjacent waters. Historical whaling records show that the highest catch per unit effort occurred there (Bockstoce and Botkin 1983). Although subject to several biases, these data still indicate that this area traditionally supported bowhead whales. Whales have been observed as far east as Holman Island (Hazard and Cubbage 1982) on the eastern shore of Amundsen Gulf. If the correlation between whale length and longitude

described earlier is valid for the region outside the present study area, large animals would be expected to occur in the Amundsen Gulf area.

The size distribution of photographically sampled whales has remained fairly constant since 1983 despite changes in techniques and equipment. This consistency suggests site fidelity in certain age classes of bowhead whales, but it could also reflect the influence of some proximate factor that affects bowhead behaviour similarly each year. These factors may have changed since 1982, the last year when adult whales were relatively abundant in the Mackenzie Bay area.

The reasons for age-class segregation of the bowhead population on its summer range are at present unknown. It has been suggested that there may be a differential response among whales of different age classes to disturbance from offshore industrial activities, resulting in the displacement of larger, older animals to areas outside of the industrial zone (Indian and Northern Affairs Canada and Environment Canada 1987). However, there is also evidence that segregation of the population is a natural phenomenon independent of influence from human activities.

Some of the results of this study suggest that industrial activities may have a differential effect on the distribution of size classes of bowhead whales. Results of multivariate analysis show that bowhead whale length is significantly correlated to distance from industrial activity. However, when the animals found in Franklin Bay are removed from consideration, the significance of distance from industrial activities is lost in the model. Thus, either industrial activity has had no effect on age-class segregation within the industrial zone, or activities associated with hydrocarbon exploration have repelled older animals to areas completely outside the zone of industrial influence.

Additional evidence of potential industrial influence on bowhead whale distribution comes from the observation that larger animals occurred in the industrial zone in 1980, the first year of intensive bowhead surveys in the area, than have been found there since that time. As discussed earlier, the distribution of bowheads in the southeast Beaufort Sea in 1980 appears anomalous, with large numbers of whales occurring off the western Tuktoyaktuk Peninsula. Spring migration in 1980 was delayed by several weeks (Ljungblad et al. 1986b), which might have altered the normal pattern of whale distribution and segregation in the late summer of 1980.

Information on the migratory behaviour of bowheads, as well as observations of other mysticete populations, suggest that size segregation may be a natural phenomenon independent of human activities. The spring migration of bowheads off Alaska is segregated according to age,[4] which may persist into the late summer feeding period. During the historical whaling period, the largest animals were taken late in the season (Bockstoce 1987), suggesting that this component of the population was the last to leave the area during

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[4] M. Nerini, National Marine Mammal Laboratory, Seattle, WA, personal communication, 1986.

the fall migration. Segregation of age and sex classes during migration has been well documented in a variety of baleen whales (Bannister and Gambell 1965; Dawbin 1966; Poole 1984), and some species may also be segregated on summer feeding grounds (Mackintosh 1966; Tarasevich 1967; Bogoslavskaya et al. 1981). Bowheads in the eastern Canadian Arctic also appear to be segregated according to age class during late summer (Finley et al. 1986).

Segregation of bowheads on their summer feeding grounds may also be related to differential feeding preferences. It has been speculated that younger whales may have different baleen structure than adults, enabling them to feed more efficiently on small copepods such as those present along the Yukon coast (Duval 1986). Adult bowheads may feed more extensively on euphausiids and larger marine copepods present in the water column in deeper waters. Evidence from stomach content analyses suggests that different-sized whales may feed preferentially on different food, with younger animals feeding on epibenthic organisms to a greater extent than adults (Lowry and Frost 1987).

FACTORS DETERMINING BOWHEAD WHALE DISTRIBUTION IN THE SOUTHEAST BEAUFORT SEA

As discussed earlier, two hypotheses have been proposed to explain the annual variability in the distribution of bowhead whales in the southeast Beaufort Sea during the late summer (Indian and Northern Affairs Canada and Environment Canada, 1984, 1985, 1987). The first is that behavioural disturbance caused by activities associated with petroleum exploration in the region has resulted in bowheads avoiding the industrial zone off the Mackenzie River delta and eastern Tuktoyaktuk Peninsula. The second is that the distribution of bowheads is determined by natural oceanographic factors which vary within and between years. These factors influence the distribution and abundance of zooplankton, which in turn affect bowhead movements during the late-summer feeding season.

Information relevant to these two hypotheses has been reviewed in detail during annual workshops of the Beaufort Environmental Monitoring Project (Indian and Northern Affairs Canada and Environment Canada 1984, 1985, 1987), and by Richardson et al. (1985), Duval (1986), Thomson et al. (1986), and Ward and Pessah (1986). Evidence is increasing that bowheads in the southeast Beaufort Sea congregate in areas of high zooplankton density, the locations of which are determined by oceanographic and meteorological factors specific to a given year (Borstad 1985; Harwood and Borstad 1985; Duval 1986). An important variable is the location of the Mackenzie River plume, which is expected to provide poor habitat for zooplankton (Thomson et al. 1986). In most years, the plume encompasses most of the area of offshore industrial activity.

The present study provides further evidence in support of the hypothesis that bowhead distribution is controlled largely by the availability of food. Most bowheads observed during the late August and September surveys in 1986 were located in areas where zooplankton densities would be expected to be high, namely, along the Yukon coast, at the interface between cold waters of the Beaufort Sea and the Mackenzie River plume, and on the eastern Tuktoyaktuk shelf. The results of the food-availability study completed at the same time

are expected to confirm that zooplankton densities were relatively high in each of these areas (Bradstreet et al. 1987).

In 1986, bowheads were again uncommon in the region in which industrial activity has been concentrated in recent years, despite a considerable reduction in the level of activity. It seems likely, therefore, that whale distribution in 1986 was determined primarily by natural factors. However, it might still be argued that bowheads have continued to avoid the industrial zone as a result of prior experience.

The present study was designed to coincide spatially and temporally with an investigation of bowhead food availability in the same study area (Bradstreet et al. 1987). Information on the distribution, abundance, and species composition of zooplankton was collected from areas where bowheads were feeding (the Yukon coast and Mackenzie Bay estuarine fronts) as well as from areas within the industrial zone where no bowheads were present. Together, the results of these two studies should help to determine the extent to which the distribution of bowheads in 1986 was influenced by the location of their food, and ultimately should contribute significantly to our understanding of the factors controlling the distribution patterns of bowheads in the southeast Beaufort Sea.

APPENDIX A

TRANSECT LOCATION AND SURVEY DATES

Survey 1: 25 August - 01 September 1986

Zone	Transect number	Survey date	Longitude (°W)	Latitude (°N) South end	Latitude (°N) North end	Transect length (km)[a]
Yukon	2	25	140°11.9'	69°36.2'	70°25.1'	72.1
	3	25	139°39.8'	69°35.1'	70°26.4'	88.4
	4	25	139°07.7'	69°38.0'	70°21.8'	67.1
	5	25	138°37.0'	69°18.6'	70°16.6'	101.0
	6	26	138°06.5'	69°08.5'	69°41.5'	61.2
	7	26	137°34.7'	69°02.0'	69°34.2'	59.3
Delta	8	26	137°02.8'	69°02.2'	70°36.8'	163.8
	9	26	136°31.1'	69°17.1'	70°40.1'	152.3
	10	26	136°00.0'	69°29.1'	70°47.4'	145.1
	11	26	135°28.7'	69°39.6'	70°52.8'	126.9
	12	29	134°57.2'	69°41.7'	70°35.0'	81.9
	13	29	134°24.2'	69°44.2'	70°35.0'	70.0
	14	29	133°53.9'	69°39.5'	70°50.0'	126.0
	15	29	133°23.2'	69°38.1'	70°50.0'	124.7
Tuk Pen	16	31	132°50.8'	69°39.5'	70°45.0'	97.1
	17	31	132°19.9'	69°48.8'	70°45.0'	67.6
	18	31	131°47.9'	69°51.6'	71°07.0'	116.2
	19	31	131°17.2'	70°00.0'	71°08.1'	97.1
	20	31	130°46.1'	70°10.2'	71°00.0'	85.4
	21	31	130°14.9'	70°10.2'	71°00.0'	80.6
	22	31	129°42.1'	70°16.9'	71°05.0'	79.7
	23	31	129°09.8'	70°02.9'	71°05.0'	109.0
	24	01	128°39.9'	69°51.2'	71°27.0'	168.1
West Amundsen	25	01	128°08.8'	70°36.5'	71°27.0'	81.7
	26	01	127°34.2'	71°06.5'	71°36'.5'	0

APPENDIX A (continued)

Survey 2: 07 - 14 September 1986

Zone	Transect number	Survey date	Longitude (°W)	Latitude (°N) South end	Latitude (°N) North end	Transect length (km)[a]
Yukon	1	07	140°42.9'	69°37.2'	70°20.0'	79.3
	2	07	140°11.9'	69°36.2'	70°20.0'	81.2
	3	07	139°39.8'	69°35.1'	70°20.0'	83.2
	4	07	139°07.7'	69°38.0'	70°20.0'	77.8
	5	07	138°37.0'	69°18.6'	70°20.0'	113.8
	6	07	138°06.5'	69°08.5'	70°20.0'	132.5
	7	07	137°34.7'	69°02.0'	70°20.0'	144.2
Delta	8	07	137°02.8'	69°02.2'	70°20.0'	144.2
	9	08	136°31.1'	69°17.1'	70°20.0'	0
	10	08	136°00.0'	69°29.1'	70°20.0'	0
	11	10	135°28.7'	69°39.6'	70°53.8'	136.4
	12	10	134°57.2'	69°41.7'	71°03.3'	151.2
	13	10	134°24.2'	69°44.2'	71°08.7'	156.6
	14	10	133°53.9'	69°39.5'	71°10.5'	168.6
	15	10	133°23.2'	69°38.1'	71°14.4'	145.8
Tuk Pen	16	10	132°50.8'	69°39.5'	71°08.6'	165.1
	17	10	132°19.9'	69°48.8'	71°06.3'	143.6
	18	10	131°47.9'	69°51.6'	71°09.6'	144.5
	19	14	131°17.2	70°00.0'	71°30.0'	166.8
	20	14	130°46.1'	70°10.9'	71°33.2'	152.5
	21	14	130°14.9'	70°10.2'	71°42.3'	170.7
	22	14	129°42.1'	70°16.9'	71°42.0'	157.7
	23	14	129°09.8'	70°03.2'	71°42.0'	183.1
	24	14	128°39.9'	69°59.2'	71°36.5'	180.3

[a] Transect length following removal of unsurveyed portions.

APPENDIX B

EFFECTIVE TRANSECT WIDTH

The strip transect method was used to estimate the abundance of bowheads recorded during systematic surveys. This method assumes that whales were equally detectable over the entire transect width, which was 1,000 m on each side of the aircraft (total width = 2,000 m). To test the validity of this assumption, the lateral distance from the flight path was measured with an inclinometer for 73 bowhead sightings from 1986 and analysed for consistency across the transect width.

The frequency distributions of sighting distances for both the late August and early September surveys were plotted at 100 m intervals (Figure B-1). Of 52 whales sighted on-transect, 29 (56 per cent) were in the inner half of the transect (0-500 m) and 23 (44 per cent) were in the outer half. These proportions were not significantly different (chi-squared = 0.69, df = 1, $p > 0.30$), suggesting that the detectability of whales was similar across the transect.

Additional evidence that bowheads have uniform detectability across the 1,000-m transect width was obtained by examining the overall distribution of 327 sightings from systematic surveys conducted in 1981, 1982, 1984, 1985, and 1986 (Davis et al. 1982; Harwood and Ford 1983; Harwood and Borstad 1985; Duval 1986; present study). The resultant distribution indicated that sightings had a relatively consistent frequency of occurrence to a range of 1,000 m, and then tended to decrease at greater distances (Figure B-2). An analysis of the observed and expected frequencies of sightings recorded in each 100-m interval between 0 and 1,000 m detected no statistical variation from a random model (chi-squared = 5.85, df = 9, $p > 0.50$, n = 270 sightings).

On the basis of these analyses, it is concluded that the assumption of equal detectability of bowheads across a 1000-m transect width is unlikely to have biased the population estimates calculated during the present investigation.

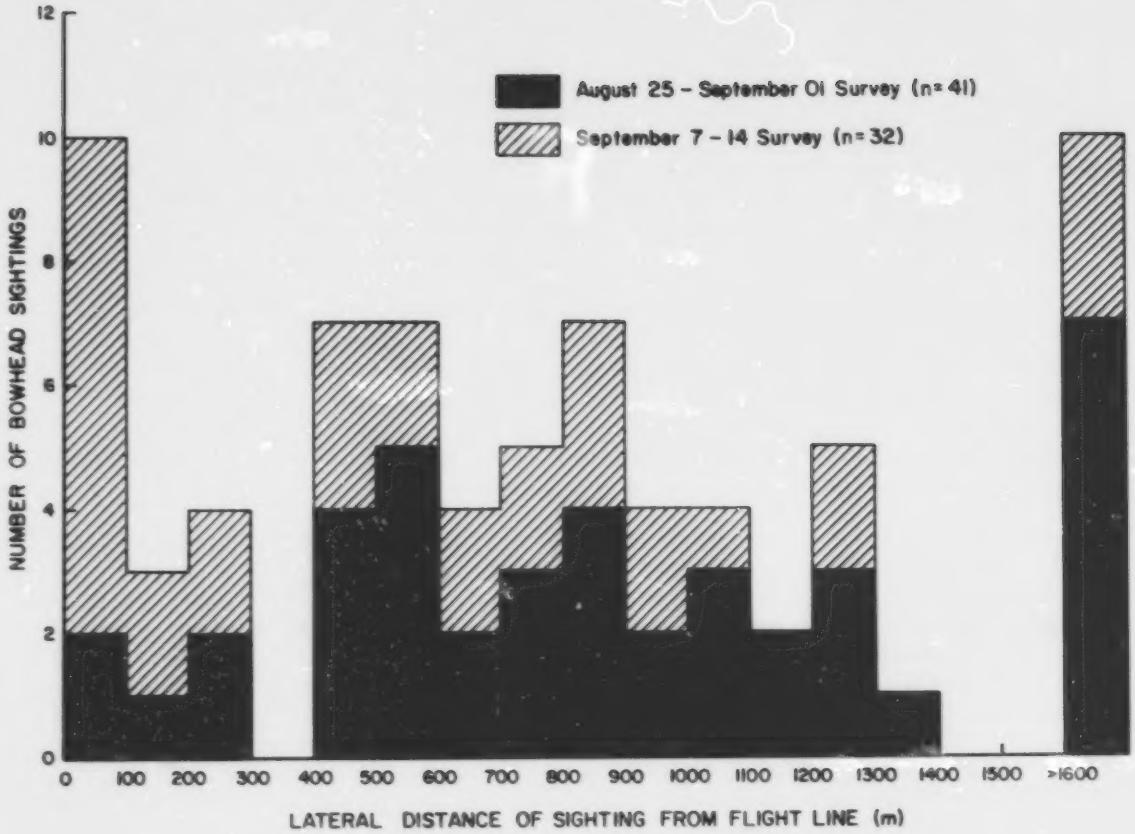

Figure B-1. Comparative distribution of on-transect bowhead sightings across the transect width in 1986.

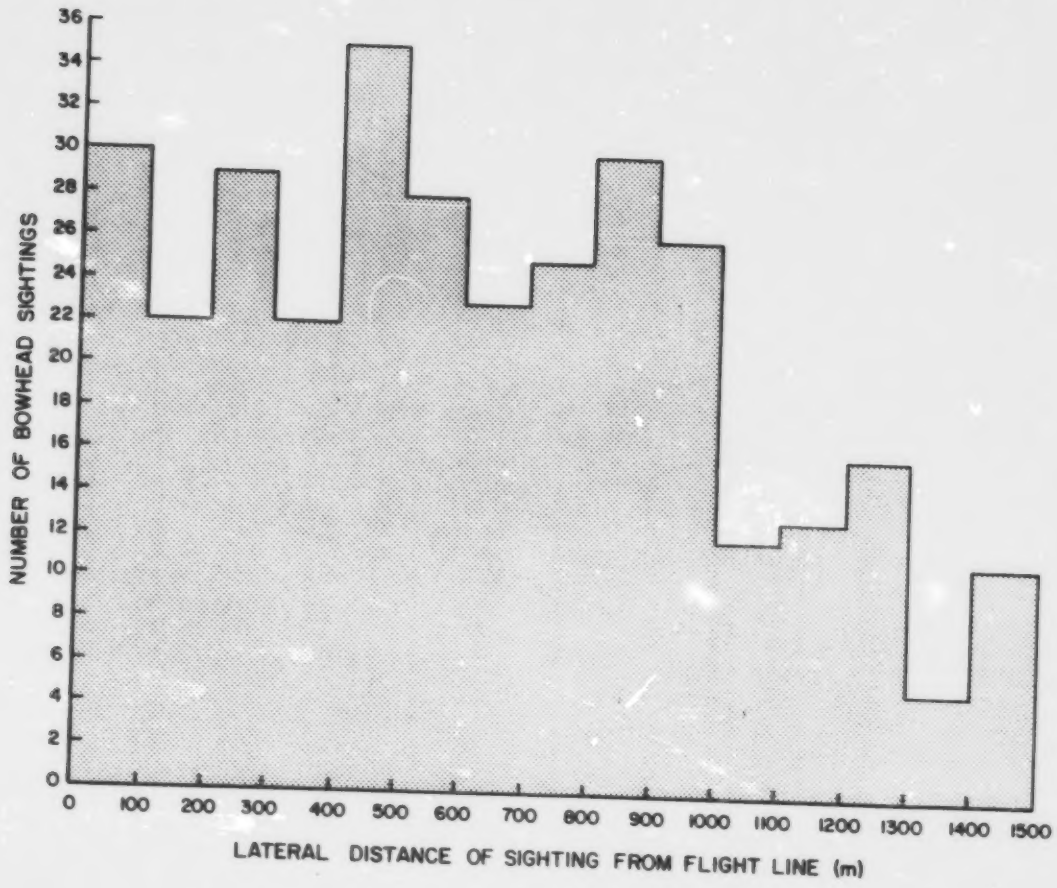

Figure B-2. Frequency distribution of on-transect bowhead sightings across the transect width for years 1981, 1982, 1984, 1985, and 1986 combined. Only sightings from 305 m (1,000 ft) altitude included. N = 327 sightings. See text for data sources.

APPENDIX C

LOCATIONS OF BOWHEADS SIGHTED ON AND OFF-TRANSECT DURING SYSTEMATIC SURVEYS, LATE AUGUST-EARLY SEPTEMBER, 1986

Date	Line #	On/Off transect	No. of Whales	Latitude (°N)	Longitude (°W)
25 Aug	2	Off	1	70°00.3'	140°11.9'
25 Aug	3	On	1	69°35.5'	139°39.8'
25 Aug	5	On	1	69°24.9'	138°37.0'
26 Aug	7	On	1	69°09.9'	137°34.7'
26 Aug	7	Off	1	69°09.1'	137°34.7'
26 Aug	7	On	1	69°09.3'	137°34.7'
26 Aug	8	On	1	69°21.6'	137°02.8'
26 Aug	8	On	1	69°21.6'	137°02.8'
26 Aug	8	Off	1	69°21.6'	137°02.8'
26 Aug	8	On	1	69°23.3'	137°02.8'
26 Aug	9	Off	1	69°49.4'	136°31.1'
26 Aug	9	On	1	69°41.8'	136°31.1'
26 Aug	9	On	2	69°38.7'	136°31.1'
26 Aug	9	Off	1	69°37.8'	136°31.1'
26 Aug	9	On	1	69°37.1'	136°31.1'
26 Aug	9	Off	2	69°53.8'	136°31.1'
26 Aug	9	On	1	69°50.5'	136°31.1'
26 Aug	10	Off	1	69°54.5'	136°00.0'
31 Aug	16	On	1	69°39.5'	132°50.8'
31 Aug	18	Off	1	70°31.2	131°47.9'
31 Aug	18	On	3	70°51.5'	131°47.9'
31 Aug	18	On	1	70°54.7'	131°47.9'
31 Aug	19	Off	1	70°47.6'	131°17.2'
31 Aug	19	Off	1	70°36.8'	131°17.2'
31 Aug	19	On	1	70°34.1'	131°17.2'
31 Aug	19	On	1	70°32.8'	131°17.2'
31 Aug	19	Off	1	70°32.5'	131°17.2'
31 Aug	19	Off	1	70°45.8'	131°17.2'
31 Aug	19	On	1	70°39.9'	131°17.2'
31 Aug	20	Off	1	70°28.9'	130°46.1'
31 Aug	20	On	1	70°41.7'	130°46.1'
31 Aug	20	Off	1	70°42.6'	130°46.1'
31 Aug	20	Off	3	70°43.6'	130°46.1'
31 Aug	20	On	2	70°45.7'	130°46.1'
31 Aug	20	On	1	70°46.1'	130°46.1'
31 Aug	20	Off	1	70°46.3'	130°46.1'
31 Aug	20	Off	1	70°46.5'	130°46.1'
31 Aug	20	Off	2	70°49.5'	130°46.1'
31 Aug	21	On	1	70°41.8'	130°14.9'
31 Aug	21	On	1	70°39.6'	130°14.9'

APPENDIX C (continued)

Date	Line #	On/Off transect	No. of Whales	Latitude (°N)	Longitude (°W)
31 Aug	21	Off	1	70°33.7'	130°14.9'
31 Aug	21	Off	1	70°42.8'	130°14.9'
31 Aug	21	Off	2	70°39.1'	130°14.9'
31 Aug	21	On	2	70°33.7'	130°14.9'
31 Aug	22	On	1	70°43.6'	129°42.1'
31 Aug	22	On	1	70°43.6'	129°42.1'
31 Aug	22	Off	1	70°47.1'	129°42.1'
31 Aug	22	On	5	70°49.4'	129°42.1'
31 Aug	22	On	3	70°42.8'	129°42.8'
31 Aug	22	On	1	70°43.8'	129°42.8'
31 Aug	23	On	1	71°01.1'	129°42.1'
1 Sep	24	On	1	70°02.5'	128°39.9'
7 Sep	5	On	1	69°21.3'	138°37.0'
7 Sep	6	Off	2	69°10.2'	138°96.5'
7 Sep	6	Off	1	69°08.7'	138°96.5'
7 Sep	7	On	1	69°03.0'	137°34.7'
7 Sep	7	On	1	69°06.5'	137°34.7'
7 Sep	7	On	1	69°06.5'	137°34.7'
7 Sep	7	On	1	69°06.5'	137°34.7'
7 Sep	7	On	1	69°10.7'	137°34.7'
7 Sep	7	On	1	69°03.1'	137°34.7'
7 Sep	7	On	1	69°06.4'	137°34.7'
7 Sep	7	On	2	69°06.6'	137°34.7'
7 Sep	8	On	2	69°29.4'	137°02.8'
7 Sep	8	On	2	69°27.4'	137°02.8'
7 Sep	8	On	1	69°26.5'	137°02.8'
7 Sep	8	On	1	69°19.8'	137°02.8'
7 Sep	8	Off	1	69°04.1'	137°02.8'
10 Sep	12	On	1	70°11.9'	134°57.2'
14 Sep	19	On	1	71°03.0'	131°17.2'
14 Sep	19	On	2	71°04.5'	131°17.2'
14 Sep	20	Off	1	71°04.2'	130°46.1'
14 Sep	20	Off	1	71°01.2'	130°46.1'
14 Sep	20	Off	1	71°01.3'	130°46.1'
14 Sep	20	On	2	71°06.4'	130°46.1'
14 Sep	20	Off	1	70°40.0'	130°46.1'
14 Sep	21	On	1	70°57.7'	130°14.9'
14 Sep	21	On	1	71°00.8'	130°14.9'
14 Sep	21	On	1	71°04.4'	130°14.9'

APPENDIX C (continued)

Date	Line #	On/Off transect	No. of Whales	Latitude (°N)	Longitude (°W)
14 Sep	21	On	1	71°06.4'	130°14.9'
14 Sep	21	On	1	71°08.8'	130°14.9'
14 Sep	21	On	1	71°11.0'	130°14.9'
14 Sep	21	On	1	71°08.8'	130°14.9'
14 Sep	22	On	2	71°08.8'	130°14.9'
14 Sep	22	On	1	71°08.6'	129°42.1'
14 Sep	22	Off	1	71°08.8'	129°42.1'
14 Sep	22	On	1	71°31.9'	129°42.1'
14 Sep	22	On	3	71°08.1'	129°42.1'
14 Sep	24	On	2	71°54.2'	129°42.1'
14 Sep	24	On	1	70°45.4'	128°39.9'
14 Sep	24	On	1	70°45.1'	128°39.9'
14 Sep	24	On	1	70°57.5'	128°39.9'
			1	71°26.9'	128°39.9'

APPENDIX D

LENGTHS AND LOCATIONS OF WHALES PHOTOGRAPHED IN 1986. ANIMALS WITH RESOLUTION AND FLEX GRADES WORSE THAN 3 FOR MORE THAN HALF THE OBSERVATIONS ARE NOT INCLUDED.

Photo No.	Date	Lat (°N)	Long (°W)	Length (m)
0100	8/25/86	69°38.3'	139°06.8'	10.53
0130	8/25/86	69°38.2'	139°08.5'	9.77
0140	8/25/86	69°38.3'	139°06.8'	9.26
0170	8/25/86	69°38.6'	139°07.4'	12.18
0180	8/25/86	69°38.9'	139°07.2'	8.90
0190	8/25/86	69°38.7'	139°09.3'	10.48
0230	8/25/86	69°36.2'	139°15.2'	7.99
0270	8/25/86	69°36.2'	139°18.9'	12.32
0290	8/25/86	69°36.0'	139°20.5'	9.09
0311	8/25/86	69°35.7'	139°16.3'	9.79
0330	8/25/86	69°37.2'	139°19.4'	8.81
0351	8/25/86	69°35.6'	139°19.0'	10.58
0410	8/25/86	69°35.8'	139°18.0'	8.51
0450	8/25/86	69°35.7'	139°17.1'	10.50
0471	8/25/86	69°35.3'	139°17.4'	8.51
0472	8/25/86	69°35.3'	139°17.4'	10.25
0630	8/26/86	69°06.3'	137°36.9'	8.84
0660	8/26/86	69°07.3'	137°35.9'	8.79
0700	8/26/86	69°06.7'	137°37.4'	8.61
0780	8/26/86	69°06.6'	137°39.7'	7.94
0800	8/26/86	69°06.3'	137°36.2'	9.74
0820	8/26/86	69°06.8'	137°37.3'	8.78
0900	8/26/86	69°24.0'	137°10.8'	9.37
0910	8/26/86	69°23.5'	137°11.0'	8.87
0920	8/26/86	69°23.6'	137°13.6'	12.65
0930	8/26/86	69°23.5'	137°14.1'	11.64
0940	8/26/86	69°23.5'	137°12.7'	10.66
0950	8/26/86	69°21.5'	137°16.0'	8.96
0960	8/26/86	69°21.3'	137°16.0'	12.14
0980	8/26/86	69°25.6'	137°09.8'	10.80
0990	8/26/86	69°24.4'	137°10.5'	7.47
1000	8/26/86	69°23.1'	137°10.2'	8.47
1010	8/26/86	69°23.1'	137°09.9'	8.42
1060	8/26/86	69°23.6'	137°09.0'	11.13
1070	8/26/86	69°22.1'	137°13.5'	11.01
1080	8/26/86	69°20.6'	137°15.9'	10.12
1130	8/26/86	69°22.5'	137°13.3'	10.84
1140	8/26/86	69°22.5'	137°13.9'	9.01
1150	8/26/86	69°25.0'	137°09.9'	10.52
1170	8/26/86	69°23.2'	137°11.0'	10.46
1200	8/31/86	70°32.3'	131°06.7'	8.73

APPENDIX D (continued)

Photo No.	Date	Lat (°N)	Long (°W)	Length (m)
1210	8/31/86	70°32.5'	131°08.6'	11.99
1230	8/31/86	70°31.8'	130°51.4'	10.60
1250	8/31/86	70°38.5'	130°45.2'	12.98
1270	8/31/86	70°38.6'	130°44.5'	10.43
1310	8/31/86	70°38.7'	130°49.6'	11.47
1400	8/31/86	70°37.6'	130°47.6'	12.58
1450	8/31/86	70°37.3'	130°51.5'	10.61
1470	8/31/86	70°38.5'	130°44.2'	12.84
1500	8/31/86	70°41.6'	130°52.6'	9.63
1510	8/31/86	70°42.3'	130°53.0'	9.41
1520	8/31/86	70°42.8'	130°55.7'	6.97
1541	8/31/86	70°44.4'	130°50.6'	13.80
1551	8/31/86	70°44.3'	130°51.3'	10.53
1552	8/31/86	70°44.3'	130°51.3'	13.94
1560	8/31/86	70°44.3'	130°51.0'	13.54
1570	8/31/86	70°44.5'	130°50.3'	10.40
1580	8/31/86	70°44.5'	130°49.8'	12.48
1590	8/31/86	70°45.6'	130°48.7'	8.81
1610	8/31/86	70°44.5'	130°51.1'	12.53
1622	8/31/86	70°44.7'	130°51.0'	12.56
1630	8/31/86	70°43.0'	130°52.2'	14.94
1641	8/31/86	70°43.6'	130°50.6'	15.45
1642	8/31/86	70°43.6'	130°50.6'	6.91
1660	8/31/86	70°44.6'	130°50.3'	13.88
1680	8/31/86	70°44.6'	130°51.1'	9.00
1700	8/31/86	70°45.7'	130°50.5'	8.65
1720	8/31/86	70°44.8'	130°50.7'	12.51
1751	8/31/86	70°44.5'	130°50.8'	10.63
1752	8/31/86	70°44.5'	130°50.8'	9.92
1771	8/31/86	70°45.1'	130°50.2'	7.05
1772	8/31/86	70°45.1'	130°50.2'	10.14
1791	8/31/86	70°44.7'	130°50.9'	9.48
1793	8/31/86	70°44.7'	130°50.9'	9.70
1802	8/31/86	70°44.4'	130°50.0'	7.83
1810	8/31/86	70°44.3'	130°51.8'	15.16
1831	8/31/86	70°50.1'	129°41.9'	8.72
1832	8/31/86	70°50.1'	129°41.9'	8.07
1850	8/31/86	70°42.2'	129°43.4'	15.29
1880	8/31/86	70°41.8'	129°44.3'	7.86
1892	8/31/86	70°41.8'	129°45.6'	11.11
1931	8/31/86	70°42.9'	129°43.4'	14.60
1932	8/31/86	70°42.9'	129°43.4'	6.16
2210	9/01/86	70°42.3'	131°10.6'	12.15
2220	9/01/86	70°41.8'	130°56.2'	9.74
2230	9/01/86	70°39.3'	130°25.0'	14.37

APPENDIX D (continued)

Photo No.	Date	Lat (°N)	Long (°W)	Length (m)
2250	9/01/86	70°47.8'	129°33.4'	11.51
2261	9/01/86	70°48.3'	129°35.9'	11.35
2262	9/01/86	70°48.3'	129°35.9'	13.17
2280	9/01/86	70°48.2'	129°33.1'	6.70
2290	9/01/86	70°48.4'	129°34.5'	15.11
2300	9/01/86	70°48.3'	129°33.2'	12.27
2310	9/01/86	70°48.3'	129°32.4'	12.10
2321	9/01/86	70°48.6'	129°34.7'	11.12
2330	9/01/86	70°48.4'	129°32.8'	11.05
2350	9/01/86	70°47.7'	129°26.4'	16.18
2372	9/01/86	70°47.9'	129°31.9'	11.68
2381	9/01/86	70°48.4'	129°31.5'	13.06
2390	9/01/86	70°48.2'	129°32.8'	8.31
2401	9/01/86	70°47.8'	129°30.0'	14.34
2410	9/01/86	70°48.1'	129°31.1'	10.90
2430	9/01/86	70°48.2'	129°31.6'	13.36
2440	9/01/86	70°48.2'	129°33.0'	15.18
2462	9/01/86	70°48.0'	129°30.4'	11.88
2470	9/01/86	70°48.0'	129°30.9'	11.52
2482	9/01/86	70°48.3'	129°30.5'	13.76
2490	9/01/86	70°48.2'	129°28.4'	8.53
2500	9/01/86	70°48.3'	129°30.6'	12.28
2600	9/01/86	70°40.7'	128°29.3'	14.30

APPENDIX E

WHITE WHALE SIGHTINGS RECORDED DURING BOWHEAD SURVEYS AND BY INDUSTRY PERSONNEL

Results of Systematic Surveys

Any observations of white whales were recorded during the 1986 systematic surveys. Twenty-one animals were sighted during the late August survey. Sixteen of these (13 adults, 1 juvenile, and 2 calves) were on-transect and five (4 adults and 1 calf) were recorded either off-transect or during ferrying flights. During the early September survey, 23 white whales were recorded, 11 of these were on-transect (8 adults, 2 juveniles, and 1 calf) and 12 (11 adults and 1 calf) either off-transect or observed while ferrying. The locations of these sightings are shown in Figures E-1 (late August) and E-2 (early September).

Because of the low number of sightings of white whales, few trends in distribution or movements in the region were apparent. Seventeen of the whales occurred in offshore waters (north of 70°N) north of the Yukon, and five were sighted in the vicinity of feeding bowheads close to the Yukon coast between Shingle and King points.

Sightings by Industry Personnel

Industry personnel reported five sightings (30 white whales) between 21 June and 14 July 1986 (see Appendix F). All sightings occurred in the area of offshore exploration activity north of Kugmallit Bay. One sighting was of three whales that remained within about 1.4 km of the vessel Supplier 1 for approximately 10 min. On 25 June, a group of about 20 white whales approached within 50 m of the Molikpaq drilling unit, which was not drilling at the time.

Comments

Far fewer sightings of white whales were recorded during systematic surveys in 1986 compared to similar surveys in recent years. Total numbers of animals recorded during late August and early September surveys in 1982-1986 are listed in Table E-1. In past years, more than 100 whales have been sighted during the two surveys, but less than half that number were seen in 1986. Reasons for the reduced count in 1986 are unknown, but it may be within the natural variability in abundance in the southeast Beaufort region during the late summer period.

The total number of sightings of white whales by industry personnel in 1986 was also lower than in previous years, likely due to the reduced level of offshore activity during the 1986 drilling season.

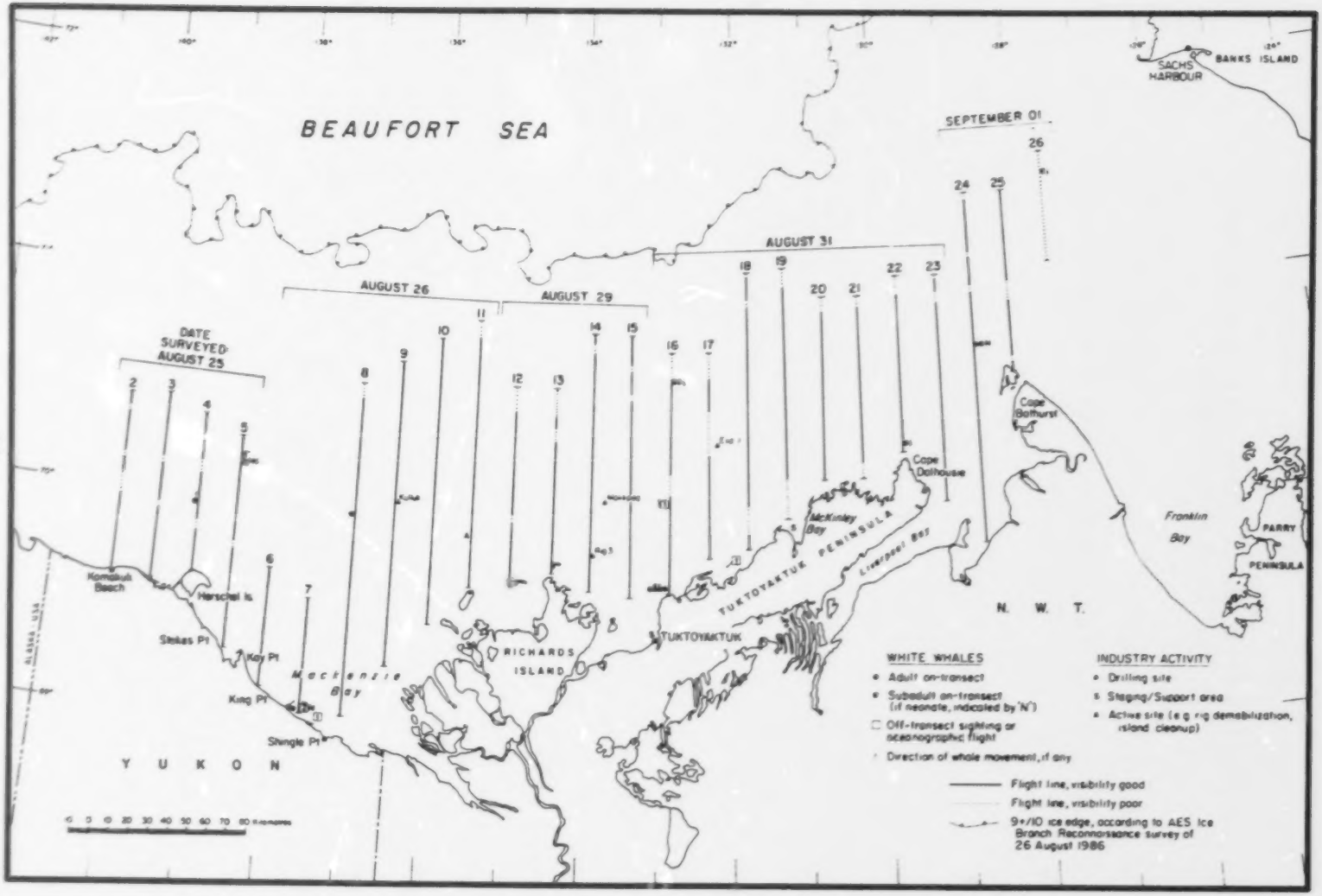

Figure E-1. Locations of white whales sighted during systematic survey conducted from 25 August to 1 September 1986.

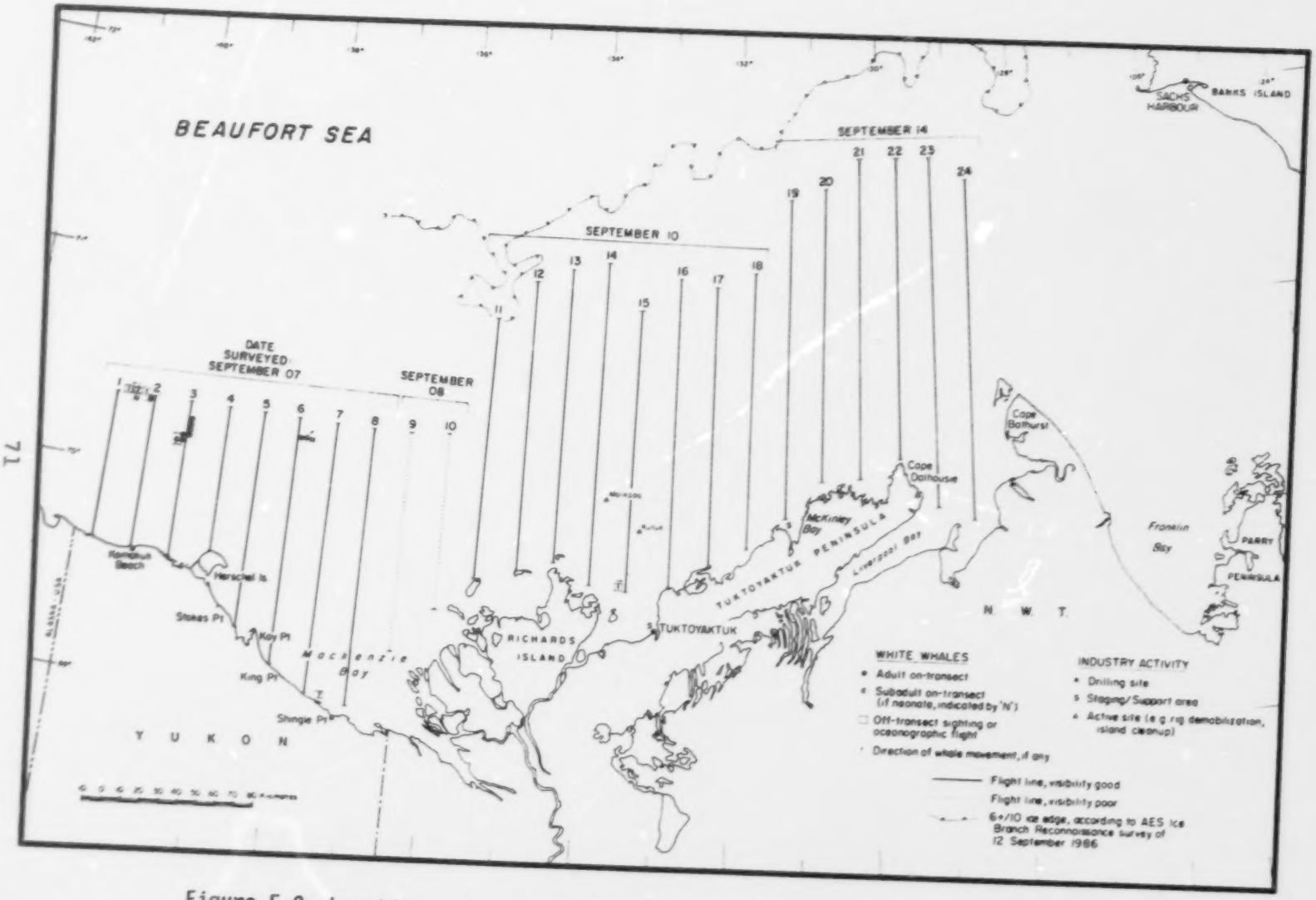

Figure E-2. Locations of white whales sighted during systematic survey conducted from 7 September to 14 September 1986.

TABLE E-1

Total numbers of white whales recorded on- and off-transect during systematic bowhead surveys, late August and early September, 1982-1986[a]

Year	No. of whales observed		
	Late Aug	Early Sept	Total
1982	85	25	110
1983	45	826	871
1984	184	47	231
1985	134	9	143
1986	21	23	44

[a] Data from Harwood and Ford (1983), McLaren and Davis (1985), Norton and Harwood (1985), Duval (1986), and present study.

APPENDIX F

WILDLIFE OBSERVATION RECORDS FOR THE 1986 DRILLING SEASON

EXPLORER I

DATE	TIME	NUMBER / SPECIES	LOCATION	COMMENTS
Whales				
Aug. 17	all day	1 bowhead	Havik B-41	Surfacing and blowing around # 7 anchor wire; seen surfacing same location most of day; surfaces every 16 or 17 min. for 2-3 min. then dives; comes back up at the same spot.
17	12:25	1 bowhead	Havik B-41	Spouting, then dove; 6' dark black fluke.
19	0555	1 bowhead	Havik B-41	Dove between ship and # 3 buoy; 15' tail spread
Seals				
July 16	0040	2 ringed seals	Havik B-41	On ice floe
16	1810	1 ringed seal	Havik B-41	On big ice floe
16	1900*	1 ringed seal	Havik B-41	Lying on ice off port bow
17	0030	2 ringed seals	Havik B-41	On ice by ship
18	0300*	2 seals	Havik B-41	On ice by starboard side
19	-	1 ringed seal	Havik B-41	In water by ship
20	-	1 seal	Havik B-41	Admiring ship[?]
21	0415	2 ringed seals	Havik B-41	Feeding off starboard side of ship
21	1945	9 ringed seals	Havik B-41	On big ice floe approximately
21	2230	2 ringed seals	Havik B-41	Port side of ship amongst ice
22	0140	1 ringed seal	Havik B-41	Swimming aft of ship
22	1900*	2 seals	Havik B-41	Port side of ship
29	1950	1 ringed seal	Havik B-41	Swimming starboard side of ship
Aug 01	0300*	1 ringed seal	Havik B-41	Swimming starboard side of ship
02	2028	1 seal	Havik B-41	Floating amongst ice floes
03	0300*	1 seal	Havik B-41	Swimming amongst ice floes
08	1710	1 seal	Havik B-41	Playing near #8 anchor wire
10	1210	1 seal	Havik B-41	Swimming near #8 anchor wire
11	2300*	1 seal	Havik B-41	By #7 wire; swimming about
15	2206	1 ringed seal	Havik B-41	Swimming about rig
18	1900*	1 ringed seal	Havik B-41	Swimming about rig
Bears				
July 30	1900*	1 polar bear	Havik B-41	On ice floe 9 n. mi. from ship
Other Sightings				
July 06	all day	30+ glaucous gulls	McKinley Bay	On ice and flying about ship
07	all day	30+ glaucous gulls	McKinley Bay	On ice and flying about ship
07	1500*	100+ common eiders	McKinley Bay	Feeding in open body of water by McKinley Island
07	0740	1 scoter	McKinley Bay	Flying across bay
08	all day	12 glaucous gulls	McKinley Bay	Around bay all day

DATE	TIME	NUMBER / SPECIES	LOCATION	COMMENTS
Other Sightings (cont.)				
08	1100*	1 scoter	McKinley Bay	Flying across bay
09	1500*	10 glaucous gulls	McKinley Bay	On ice in bay
10	1045	12 common eiders	McKinley Bay	Flying
10	all day	13 glaucous gulls	McKinley Bay	Flying about bay
10	1500*	3 black-legged kittiwakes	McKinley Bay	On ice by SSDC
11	all day	6 glaucous gulls	McKinley Bay	On ice in bay
12	1016	11 scoters	McKinley Bay	On ice in bay
12	1046	7 scoters	McKinley Bay	Flying low over ice
13	1950	9 eiders	McKinley Bay	Flying by ship
13	2115	40+ eiders	McKinley Bay	In open water in bay
13	1900*	40+ eiders	McKinley Bay	In water by SSDC
14	0500	20 eiders	McKinley Bay	Sitting on ice in bay
22	0550	2 long-tailed jaegers	Havik B-41	Flying around vessel
22	2055	1 long-tailed jaegers	Havik B-41	Flying around vessel
22	2300*	1 long-tailed jaegers	Havik B-41	Flying around ship
23	0850	2 parasitic jaegers	Havik B-41	Sitting in water by anchor wire
23	1153	1 long-tailed jaeger	Havik B-41	Flying by starboard quarter
23	1425	10 common eider	Havik B-41	Flying W
24	0450	6 eiders	Havik B-41	Flying SW
29	2010	30+ eiders	Havik B-41	Flying SW
31	2300*	1 jaeger	Havik B-41	Flew by point side of ship
Aug 02	1900*	25+ glaucous gulls	Havik B-41	Flying around supply vessel wake
03	1545	1 pomarine jaeger	Havik B-41	Flying around vessel
07	0655	2 arctic loons	Havik B-41	Flying E
07	1035	6 scoters	Havik B-41	Flying W
07	1545	20 eiders	Havik B-41	Flying E
08	0726	7 glaucous gulls	Havik B-41	Sitting in water close to ship
11	1900*	1 scoter	Havik B-41	Flying SW low over water
12	0855	1 common eider	Havik B-41	Flying W
17	1825 - 1915	2 parasitic jaegers	Havik B-41	Flying about vessel and sitting in water
18	1055	1 Skua	Havik B-41	Flying around vessel. (Probably a fulmar)
18	1115	3 scoters	Havik B-41	Flying W
18	1940	1 parasitic jaeger	Havik B-41	Flying W
19	1420	1 parasitic jaeger	Havik B-41	Flying E
22	1655	1 jaeger	Havik B-41	Flying S

SUPPLIER I

DATE	TIME	NUMBER / SPECIES	LOCATION	COMMENTS
Whales				
July 06	0620	3 belugas	69° 60°52' 133°23'	Whales within about 0.75 n.mi. of the vessel for about 10 min.
14	-	2 belugas	69°45' 132°50'	Diving up and down - - must be feeding
30	0418	1 bowhead	70°24' 132°06'	Swimming N; appeared to be adult
Aug 18	1030	3 bowheads	70°21' 132°33	
20	2020	2 whales	70°20' 132°01	Blowhole spray only
Seals				
July 27	1700	1 seal	70°20' 132°13'	Looking around
Aug 02	2319	2 seals	70°20' 132°12' 13'	Swimming

SUPPLIER 8

DATE	TIME	NUMBER / SPECIES	LOCATION	COMMENTS
Whales				
Aug 26	0630	1 beluga	70°03' 131°06'	Swimming W; very young

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
85.10.30	21:45	SEAL	1	SOUTH SIDE OF MAC. DIVED UNDER THE ICE BESIDE LEAD.
85.12.02	06:30	POLAR BEAR	1	WAS OBSERVED S.W. OF CAISSON ALONG THE EDGE OF THE WAKE. ICE THICKNESS .2-.3M.
85.12.02	21:00	POLAR BEAR	1	(POSSIBLIY THE SAME BEAR). SE SIDE, ROAMING OFF TO THE SOUTH.
85.12.03	07:00	POLAR BEAR	1	SOUTH OF THE RIG, ALONG THE WEST EDGE OF THE WAKE.
85.12.06	22:50	POLAR BEAR	1	CLOSE TO THE EAST CAISSON WALL AND TRAVERSING SOUTH VIA A SERIES OF FLOES.
85.12.07	04:30	POLAR BEAR	1	(WITH COLLAR). HUNTING AT CRACK EDGES. SOMETIMES PRONE, FACING WATER. AT TIMES PACING.
85.12.10	05:30	POLAR BEAR	1	(WITH COLLAR). PACING ALONG EAST EDGE OF CAISSON'S WAKE, SCANNING THE ICE EDGE.
85.12.10	18:00	POLAR BEAR	1	(WITH COLLAR) AROUND E & SE CAISSON AT EDGE OF OPEN LEAD.
85.12.11	03:20	POLAR BEAR	1	HUNTING SEAL ALONG CRACKS. HE BROKE THROUGH (BODILY) THIN ICE AT A SEAL BREATHING HOLE.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.01.03	09:30	RAVENS	2	PERCHED ON ICE.
86.01.12	13:30	SEAL	1	NORTH SIDE. SWIMMING AND DIVING NORTH IN OPEN LEAD BETWEEN FLOES.
86.01.12	15:00	HARBOUR & RING SEALS	12	SOUTH FACE IN OPEN WATER CREATED BY FLARE BURNER HEAT
86.01.12	16:45	ARCTIC FOX	1	NORTH OF RUBBLE PILE ON EAST FACE
86.01.29	-	POLAR BEAR	1	SIGHTED OFF THE EAST CAISSON WALL.
86.01.30	12:00	POLAR BEARS	2	LARGE ONE AND SMALL ONE KNEELING NEXT TO FROZEN CRACK ABOUT .5 MILES TO THE SW OF THE MAC.
86.02.03	13:40	POLAR BEAR	1	SPOTTED PROCEEDING NORTHWARD DURING ICE RECONNAISSANCE 10 MILES NORTH OF THE MAC
86.02.10	12:40	ARCTIC FOX	1	SEEN ON FLOE ALPHA, 7.8 NAUTICAL MILES FROM MAC AT 028°T.
86.02.18	10:00	POLAR BEAR	1	SEEN OFF OF EAST FACE HEADING EAST. APPEARED CURIOUS AND SNIFFED THE AIR FREQUENTLY. SOON LOST SIGHT OF HIM/HER(?)

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.02.21	-	POLAR BEAR	1	SEEN BY WATCHKEEPER. A LARGE MALE IN VICINITY OF RIG.
86.02.22	11:20	POLAR BEAR	2	2 ADULTS. SEEN FROM HELICOPTER DURING AN ICE RECONNAISSANCE. SIGHTINGS WERE 20 MINUTIES APART, 30 N.M. EAST OF THE RIG.
86.03.04	14:00	SEAL	1	SWIMMING IN A SMALL LEAD FORMED BY ICE DRIFTING PAST CAISSON.
86.03.05	10:30	SEAL	1	SIGHTED IN LEAD FORMING WHERE SECOND YEAR FLOE SPLIT AT THE CAISSON.
86.03.07	20:00	SEALS	2-3	COMING UP FOR AIR IN CRACKS BETWEEN ICE OF SECOND YEAR FLOE.
86.03.28	08:45	POLAR BEAR	1	SIGHTED 200M EAST OF RIG. CURIOUS. MOVED OFF TO S.W.
86.03.28	20:00	POLAR BEAR	1	PASSED MAC ON EAST SIDE.
86.03.30	14:00	POLAR BEAR	1	ADULT, PASSED BY ON THE EAST SIDE OF THE RIG.
86.04.02	07:10	POLAR BEARS	2	ADULTS, APPROACHED FROM THE N.W. AGGRESSIVE BEHAVIOUR TO EACH OTHER. LATER ONE LAID DOWN .5 MILES OFF RIG. OTHER BEAR NEAR THE CAISSON FACE HUNTING.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.04.17	21:45	SEAL	1	SWIMMING IN OPEN WATER AMONG REFREEZING NEW ICE COVER.
86.04.19	09:30	SEALS	2	ONE ADULT AND ONE BABY. DIFFERENT SIGHTINGS WITHIN 20 MINUTES. IN OPEN WATER AREAS AMONG RECENTLY FROZEN ICE COVER. (YOUNG ICE 3-7 DAYS OLD).
86.04.20	21:20	SEALS	2	MAY BE SAME SEALS SIGHTED ON 86.04.19. SEVERAL SIGHTINGS TO EAST. SEALS SURFACING IN DIFFERENT OPEN WATER AREAS AMONG SLOWLY DRIFTING YOUNG ICE.
86.04.21	21:40	SEAL	1	IN OPEN WATER AREAS, EAST SIDE. SEVERAL BREATHING HOLES IN NEW ICE (3).
86.04.22	22:20	SEALS	6	AT LEAST 3 PAIRS WERE SIGHTED SIMULTANEOUSLY IN OPEN WATER EAST OF THE RIG.
86.04.22	23:15	SEALS	2	PROBABLY TWO OF THE SIX SIGHTED EARLIER IN THE DAY.
86.04.23	15:00	SEALS	30	WERE SPOTTED BY BINOCULARS. BASKING IN THE SUN OVER A LARGE AREA WEST OF THE RIG.
86.04.24	09:00	SEALS	4	SPOTTED SEALS TO THE S.E. IN OPEN WATER LEFT BY RIG WAKE.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.04.24	21:00	SEAL	1	IN CRACK 30' FROM SW-W CORNER OF RIG. ICE WAS ACTIVELY DRIFTING TO EAST.
86.04.25	18:30	SEALS	15	BASKING IN SUN TO N-NW OF RIG.
86.04.26	14:00	BUNTING	1	ALIGHTED ON RIG.
86.04.26	18:00	SEALS	8	BASKING ON ICE, NE SIDE
86.04.29	21:00	SEALS	2	BASKING ON ICE BESIDE LEAD
86.04.30	04:00	POLAR BEAR	1	SPOTTED SEARCHING THE EDGE OF A LEAD
86.04.30	23:00	POLAR BEAR	1	VERY LARGE. SIGHTED OFF OF EAST FACE. CURIOUS - WANDERED NORTH.
86.05.12	13:30	POLAR BEARS	3	SIGHTED 4 N.M. NORTH OF RIG. MOTHER AND 2 CUBS. (1 CUB OLDER THAN THE OTHER). SEVERAL FRESH SEAL KILLS. FISHING IN NARROW LEAD/CRACK (3-4' WIDE) BETWEEN RIDGED ICE.
86.05.12	13:40	POLAR BEAR	1	FISHING FOR SEALS 5 NAUTICAL MILES NORTH OF THE RIG.
86.05.14	22:00	RING SEALS	4	VARIOUS LOCATIONS AROUND RIG IN OPEN LEADS. MANY BREATHING HOLES.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.05.16	22:00	SEALS	5-6	VARIOUS LOCATIONS AROUND RIG IN OPEN LEADS.
86.05.18	14:00	POLAR BEAR	1	SIGHTED ON SMALL FLOE 40NM NORTHEAST OF AMAULIGAK. ICE TEAM WORKING ON ICE INSTALLING ARGOS BUOY #9057. DID NOT REALIZE BEAR WAS APPROACHING JUST OVER NEXT RIDGE UNTIL HELICOPTER IN AIR. TRIED TO SCARE BEAR AWAY FROM BUOY.
86.05.20	01:00	SEALS	8	IN LEAD JUST NORTH OF RIG. PLAYING IN SMALL PATCH OF OPEN WATER CREATED BY ICE MOVEMENT AROUND RIG.
86.05.21	AFTERNOON	POLAR BEAR	1	SEEN SOUTH OF RIG LOOKING FOR SEALS. TRACKS VISIBLE ORIGINATING 10 METRES FROM RIG AMD BESIDE LEAD FOR APPROXIMATELY 100 METRES WHERE POLAR BEAR APPARENTLY WENT BACK INTO WATER.
86.05.22	0000	POLAR BEAR	1	WALKING UP AND DOWN ICE BESIDE LEAD OF NORTHERN FACE OF RIG. LAID DOWN AT ICE EDGE WAITING FOR TWO SEALS IN OPEN WATER. PROBABLY A MALE - EST 9' IN LENGTH, APPARENTLY IN QUITE GOOD HEALTH.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.05.24	AFTERNOON	POLAR BEARS	2	WERE CHASING EACH OTHER ACROSS THE ICE JUST OFF THE RIG.
86.05.28	20:30	POLAR BEAR	1	SOUTHWEST OF RIG APPROXIMATELY 6 NAUTICAL MILES.
86.05.29	04:30	POLAR BEAR	3	MOTHER AND TWO CUBS JUST OFF NORTH SIDE OF CAISSON.
86.06.01	03:30	SEALS	3	ALL ON TOP OF REFROZEN THIN 1ST YEAR ICE. ONE .5 NM WEST OF RIG APPEARS LIFELESS. OTHER TWO SHOWED MOVEMENT BY SITTING UP (OBSERVED THROUGH BINOCULARS) NOT SURE OF THEIR SITUATION.
86.06.05	06:00	SEALS	6	EAST OF RIG IN OPEN WATER PATCH. COMING UP FOR AIR AND LOOKING AT THE RIG.
86.06.06	02:00	SEAGULLS	3	NORTH SIDE - SWIMMING IN WATER AND ONE ON ICE EDGE. SPECIES NOT KNOWN.
86.06.06	05:30	SEAL	1	RING SEAL - SOUTH SIDE OF RIG BETWEEN ICE FLOES IN OPEN WATER.
86.06.21	03:00	BELUGA WHALE	1	SIGHTED BY TERRY FOX WHILE ON ROUTE FROM THE MAC TO THE KULLUK. JUST OFF SHIP'S PORT SIDE.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.06.25	21:00	BELUGA WHALES	EST 20	SWIMMING WESTWARD AND COMING TO SURFACE "LAZILY". SEEMED CURIOUS OF THE RIG - WITHIN 50 METRES OF NORTH FACE (NOT DRILLING - DOING WELL FLOW TEST).
86.06.25	21:40	BELUGA WHALES	4	SEEM TO BE COMING UP FOR AIR BETWEEN ICE FLOES 20-100 METRES OFF OF NE FACE. CLOSE TO THE RIG DESPITE OPEN WATER 400 METRES NORTH AND EAST OF RIG. NO APPARENT HEADING - REMAINING NEAR RIG.
86.07.11	09:45	SEAL	1	SWIMMING BETWEEN FLOES TO THE EAST.
86.07.14	14:10	RINGED SEALS	8	6 ADULTS AND 2 PUPS ON ICE FLOE BESIDE RIG.
86.07.15	13:00	RINGED SEALS	28-35	SCATTERED ABOUT ON FLOE (1.5 NM WIDE). SEVERAL WERE PUPS.
86.07.15	LATE EVENING	ARCTIC FOX	2	TWO SEPARATE INCIDENTS OF A FOX ON A FLOE PASSING BY THE RIG. ONE TO THE NORTH AND ONE TO THE SOUTH.
86.07.27	08:08	RINGED SEAL	1	50 METRES OFF NORTH FACE. CRUISED AROUND FOR .5 HOURS AND THEN DEPARTED.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.07.28	03:00	RINGED SEALS	3	ON ICE FLOE APPROXIMATELY 200 METRES SOUTH OF RIG - LAZING IN THE SUN.
86.07.30	04:50	SEALS	2	APPROXIMATLEY 20 METRES OFF NE CORNER. ON SURFACE FOR 10 MINUTES.
86.07.30	13:30	SCOTERS	50+	IN WATER 10 NM SOUTH OF MAC. SPOTTED BY S-61 - 400' A.S.L.
86.07.30	21:30	POLAR BEARS	3	ON ICE FLOE (DEN?). FLOE BROKEN BY ICE BREAKERS.
86.07.31	06:00	SCOTER	1	FLYING LOW OVER WATER, HEADING EAST.
86.08.02	21:30	RINGED SEAL	1	SWIMMING.
86.08.02	23:30	SCOTERS	15-20	FLYING LOW OVER WATER, HEADING WEST.
86.08.03	14:00	POLAR BEAR	1	ADULT ON BROKEN ICE FLOE
86.08.08	21:00	BELUGA WHALE	1	DEAD. FLOATING 1NM NORTH OF RIG. GULLS FEEDING ON FLESH.
86.07.27	08:08	RINGED SEAL	1	50 METRES OFF NORTH FACE. CRUISED AROUND FOR .5 HOURS AND THEN DEPARTED.

WILDLIFE SIGHTINGS
AMAULIGAK ISLAND 1985/1986

DATE	TIME (MST)	SPECIES	NO.	REMARKS
86.08.08	21:00	RINGED SEAL	1	SWIMMING
86.08.11	08:45	LOON (RED THROATED)	1	FLYING WEST

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